Study on the Effectiveness of BMPs to Control Bacteria Loads

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INTRODUCTION

Buffalo and White Oak Bayous, Clear Creek, and other bodies of water in the Houston Metropolitan Area are included on the Texas 303(d) list for water quality impairments as required by the Clean Water Act. The Texas Commission on Environmental Quality (TCEQ) has initiated Total Maximum Daily Load (TMDL) projects for 47 segments in the general Houston Metropolitan Area. Local and national studies, including the TMDL for Buffalo and White Oak Bayous, have found that storm water carries a high concentration of fecal pathogens indicated by the high concentrations of *E. coli* and is a large source of the pathogen load to water bodies. Water quality management has focused on controlling storm water associated pollutants at their sources to prevent these from being transported into the storm sewer system and ultimately to the receiving water bodies. These methods, termed Best Management Practices include a wide variety of both structural and non structural strategies. Studies evaluating the effect of Best Management Practices (BMPs) on storm water quality suggest that several types of BMPs may reduce the concentrations of fecal pathogens in storm water runoff.

A wide range of practices from stenciling and street sweeping to wetland systems and wet ponds are included under the broad designation of Best Management Practices. Several BMPs, in particular, have demonstrated great potential for improving water quality. These include wet basins, dry basins, flood control/water quality basins, wetland systems, grass swales, and vegetative filter strips. Studies have shown that the mechanisms of bacteria and pathogen removal for these systems include settling/sedimentation, temperature, sunlight, and filtration (Khatiwada and Polprasert 1999; Davies and Bavor 2000; Darakas 2001; Brookes et al. 2005; Characklis et al. 2005; Gannon et al. 2005).

There are two main goals for this study. The first goal is to gather data on Houston BMPs that may be used in the implementation of TMDL projects that have been initiated for the Houston Metropolitan Area. An additional goal is to determine the effect that these have on reducing the *E. coli* load to the receiving water bodies throughout the Houston Metropolitan area.

1.1 SCOPE OF THE PROJECT

The scope of work to be performed during this study includes: (i) the identification of the BMPs available for sampling and determining the targets for sampling, (ii) the development of a strategy to sample storm water inflow and outflow, (iii) the preparation of an EPA approved Quality Assurance Project Plan (QAPP), and (iv) the analysis of data and determination of bacterial load reductions.

The six main tasks to be completed are:

1. Administer the project;
2. Participate in the stakeholder process:
3. Develop a database of the quantity and type of BMPs currently in use in the Houston-Harris County area;
4. Prepare a Work Plan/Sampling Plan;
5. Prepare a Quality Assurance Project Plan (QAPP); and
6. Gather the data.

1.2 DESCRIPTION OF THE REPORT

This document constitutes the 4th Quarterly Report for Work Order No. 5 and summarizes the activities undertaken by the University of Houston from May 2006 through August 2006.

This report reflects the progress towards the following tasks delineated in the work plan:

Task 3 – A database of the BMPs permitted by the City of Houston and Harris County has been obtained. This database was reviewed and updated to evaluate BMPs in the Houston Metro Area on the basis of several parameters that may have a bearing on the reduction of bacteria concentrations in storm water runoff.

Task 4 – Development of the Quality Assurance Project Plan (QAPP) was completed and the final QAPP is included in Appendix A.

Task 5 – The process of data collection and analysis was initiated and will continue throughout the duration of the project. The data collected were entered into a database with available descriptions so that the processes and design parameters involved in bacteria removal can be understood.

Chapter 2 of this report presents a brief discussion of the storm water permitting program, different types of BMPs, and the potential for reduction of bacteria from stormwater runoff. Chapter 3 discusses the BMP database. Chapter 4 discusses the site selection and reconnaissance activities that were performed. Chapter 5 describes the progress of sample collection activities and the results that were obtained through the date of this report. Chapter 6 details some of the future tasks to be performed for the next quarter of this study. Appendix A includes the first revision of the Quality Assurance Project Plan including the Sampling Plan.

CHAPTER 2

BEST MANAGEMENT PRACTICES

The US Environmental Protection Agency (USEPA) has focused its attention on the reduction of non point source pollutant loads into receiving waters through the use of best management practices (USEPA 2004). Much research has been performed to quantify the effect that these systems have upon receiving water quality. The large variety of BMP types and designs in addition to the importance of uncontrollable and rapidly changing environmental factors make it difficult to develop a clear understanding of the effect of these practices. Inconsistencies in sample collection procedures and data evaluation add to this problem.

BMPs can be divided according to the method of implementation into two general categories: structural and non-structural BMPs. Although the distinction between these two is not always clear, each category can help indicate the methods of contaminant reduction. The non-structural BMPs often function through the reduction of contaminant sources. One of the most common non-structural practices, for example, is public education. Through education, contaminants can be reduced by limiting littering and increasing the proper disposal of items of concern. Structural BMPs achieve contaminant reduction primarily through four processes: filtration, detention, distribution of pollutant loads over an extended period of time, and the reduction of stormwater runoff volumes discharged from a region of interest thus reducing transport capability and the associated pollutant load.

2.1 DESCRIPTION OF BMP TYPES

The evaluation of the effect of non-structural practices can require that monitoring be conducted before and after a practice is implemented. In most cases, this requires an extended and consistent period of monitoring. Even if this can be conducted, it is very difficult to determine whether any changes are the effect of the practice or other conditions. Especially in the case of fecal pathogens, environmental factors can make a large difference in ambient concentrations by affecting survival and die off rates.

For the Total Maximum Daily Load project in the Buffalo and Whiteoak Bayou watersheds, a detailed model written in HSPF is being developed to simulate the transport of fecal pathogens. The effect of many of the non-structural practices can be tested by running model scenarios that reduce these sources in the watersheds by the loads that each practice can be estimated to reduce. For example, domestic animal feces are a known source of fecal pathogens. Campaigns to have people properly dispose of fecal material are common and can be effective to reduce contamination in watersheds (NVRC 2004). By calculating the load that these animals may produce, the effect of proper disposal and thus removal from the system can be tested by removing this load from the model. Other practices have been implemented in other areas and may be tested with the model; these include street sweeping and storm drain maintenance (NVRC 2004). In addition, as part of the TMDL process for many of the other watersheds in the Houston Metropolitan region, an adequate understanding of the sources and loads in the watersheds will be developed. By reducing the loads for each source, the effect can be determined for the receiving waters.

Structural BMPs, on the other hand, depend upon the effectiveness of systems designed to reduce contaminant loads by exerting a number of specific conditions upon them. Rather than removing a specific predetermined load, these systems function to reduce a percentage of the load. In addition, these systems produce hydrologic changes such as the reduction of discharge rates and total volumes from the drainage area. Studies show important effects on fecal pathogens from many different types of structural BMPs. The most common of these in the Houston Metropolitan region include dry basins, wet basins, flood control/water quality basins, grassy swales, and vegetative filter strips. Other practices that may have important effects but are not very common to the Houston area include man made wetlands and low impact development. In addition, there are important temporary controls most commonly implemented during development and construction activities that may have important effects upon the state of water bodies. This study will focus mainly on the permanent structural systems most often permitted for water quality improvements within the Houston Metropolitan Area.

2.1.1 Dry Basins

Dry basins are structural best management practices that are designed to receive stormwater from a drainage area of interest and to discharge the water at a reduced flow rate over a determined period of time, usually 24 to 48 hours. These structures are often also referred to as dry ponds and detention ponds or basins. The Joint Task Force (JTF), composed of four government agencies that maintain the Municipal Storm Sewer System (MS4) for the Houston metro area, permits dry basins and other BMPs in the area. The JTF defines two types of basins based on the outlet design implemented: the conventional and extended detention basins. Other important design variations include the presence of vegetation or a concrete bottom, the water quality volume, the flood overflow outlet design, and the length to width ratio of the basin. Dry basins are some of the most commonly implemented structural BMPs since they are often less expensive to construct and require less maintenance than other structural systems including wet basins and artificial wetlands.

The dominant mechanisms of bacteria removal in dry basins are settling and sedimentation (JTF 2001a & b). The total reduction achieved by these processes depends on the length of detention of the stormwater runoff. Thus, a system that discharges stored volumes over a 48 hour period should be more effective than a system that discharges over 24 hours, assuming all other variables are equal. The period of detention also correlates positively with reduction of bacterial concentrations through natural decay, thermal death, exposure to solar radiation, and competition and predation from other organisms. Unfortunately, extended detention times also increase the opportunity for wildlife use and the direct deposition of feces by warm blooded animals into the stored water.

An important process that is often overlooked when evaluating detention basins is the effect of reducing bacteria loads over time and extending the period of time of the discharge to the receiving water body. During a rainfall event, the inflow and outflow rates at dry basins are affected by several variables including the size of the watershed, the amount of impervious cover, the types of soil present, and the intensity and duration of the rainfall. Dry basins decrease the natural discharge volume to the receiving water body at the peak and extend the tails of the hydrograph. This decreases the total volume of discharge and the load of bacteria (and other contaminants) discharged to the receiving water body while increasing the period of time over which the contaminants are discharged. Thus, if the load at any given time has been reduced below the maximum capacity of the stream to handle that contaminant, the body of water will fall below the regulated standard; however, if the reduced load does not decrease below this value, the period of time over which the stream is not compliant may increase.

Harris County and the City of Houston have issued permits for several types of dry basins such as dry basins with and without detention, 10/100 year basins, and dry trash basins. As shown in Table 1, Harris County has issued 309 permits for dry basins and the City of Houston has issued 167 permits for dry basins. These account for 50 percent of the total BMP permits issued by the two agencies, more than for any other type of BMP. As a result, the effectiveness of these systems may have a large effect upon the water quality of the streams in the region. Table 2 shows the total volumes and drainage areas for the different BMPs permitted in the Houston Metro Area. Dry basins are designed to accept discharge from over ten thousand acres of land in the region. This is almost half of the total for all BMPs in the region.

The effect of these types of BMPs on fecal pathogens is not commonly studied. The results of only one study were obtained while researching the effectiveness of dry basins. A dry basin was monitored by the USGS at a shopping center located at Barton Creek Square in Austin, Texas from September 1982 to September 1984. The detention pond also had a filtration system composed of fine and coarse sands and gravel that may have increased the efficiency of the system. The pond was found to remove 90% percent of the fecal coliform bacteria between the inlet and the outlet of the pond. The efficiency values from the Austin study and from studies conducted on several of the other BMP types are shown in Table 3 (ASCE 2002).

Table 1 - Existing/Permitted BMPs in Harris County

AGENCY	BEST MANAGEMENT PRACTICES (BMPs)	TYPE	COUNT
Harris County	Dry Basin	Permit	309
	Wet Basin	Permit	60
	Flood Control/Water Quality Basin	Permit	6
	Wetland	Permit	3
	Grass Swale	Permit	13
	Vegetative Filter Strips	Permit	5
	Other	Permit	193
City of Houston	Dry Basin	Permit	167
	Wet Basin	Permit	10
	Flood Control/Water Quality Basin	Permit	0
	Grass Swale	Permit	5
	Vegetative Filter Strips	Permit	2
	Other	Permit	183
	Road sweeping & minimization plans for street maintenance yards	SWMP	75% of yards
	Prevent Illicit discharges and Improper disposal	SWMP	N/A
	Industrial and high risk runoff	SWMP	N/A
	Wet screaning of area served by the MS4	SWMP	50% of total area
	Manhole cleaning, storm sewer cleaning/flushing, repairs and investigations	SWMP	N/A
Harris County Flood Control District (HCFCD)	Wet basins	SWP3	N/A
	Detention basins	SWP3	N/A
	Vegetation/Stabilization of Drainageways	SWMP	>50 miles of drainageways
	Wet Pond Extended Retrofit Sampling	SWMP	If deemed necessary
	Inlet Basket to Surge Basin	SWMP	1
	Maintenance of detention basins and drainage channels	SWMP	N/A
	Monitoring of BMPs for Water Quality	SWMP	N/A
	Trash Skimmer (Boat)	SWMP	1
	Netting overlay (at White Oak Bayou Basin Outfall)	SWMP	1
	Natural trash trap	SWMP	1
	Planted Gabion Wall	SWMP	1
Texas Department of Transportation (TxDOT)	Detention ponds	SWMP	N/A
	Pump stations	SWMP	N/A
	Grassy swales	SWMP	N/A
	Vegetative filter strips	SWMP	N/A
	Public Education Programs (Don't Mess W/ Texas, Adopt-A-Highway, etc.)	SWMP	N/A
Joint Task Force	Public Education Program	SWMP	N/A

Notes:
Permit - BMPs permitted through the JTF for stormwater quality
HCFCD - Harris County Flood Control District
SWMP - Storm Water Management Program from the NPDES Permit
SWP3 - Storm Water Pollution Prevention Plan

Table 2: Volumes and Drainage Areas of Permitted BMPs

	City of Houston Permitted BMPs				Harris County Permitted BMPs				Totals for Metro Area (acres)
	Total Volume (acre-ft)	Not Reported	Drainage Area (acres)	Not Reported	Total Volume (acre-ft)	Not Reported	Drainage Area (acres)	Not Reported	
Flood Control/Water Quality Basins	0	0	0	0	191	23	3019	0	3019
Dry Basins	1237	3	3333	1	1056	28	7305	2	10638
Grassy Swales	N/A	4	71	0	N/A	11	115	1	186
OGTs	20	165	1887	0	N/A	97	1653	0	3540
Other	3	11	117	1	25	14	604	2	721
Vegetative Filter Strips	N/A	2	23	0	N/A	4	0	0	23
Wet Basins	43	5	355	0	103	10	3340	1	3695
All Permitted BMPs	1303	190	5785	2	1375	187	16036	6	21822

Total Acreage Drained to BMPs	21822
Total sq. mi. of Harris County	1729
Total Acreage of Harris County	1106451
Total sq. mi. of project area	543
Total Acreage of Project area	347520
Percent of Harris County Served by BMPs	2.0%
Percent of Harris County Impervious Area Served by BMPs	3.9%

Table 3: Average Removal Efficiencies for Fecal Pathogen Indicators by BMP Type

BMP Tested	Sample Type	Percent Removal[1]	No of BMPs Tested	Total Samples Collected	
Dry Basin with Filter	fecal coliform	90	1	N/A	BMP Database Project [3]
Dry Basin with Filter	All2	90	1	N/A	N/A
Grassy Swale	fecal coliform	-338	1	5	Dayton Ave Project [4]
Grassy Swale	All2	-338	1	5	N/A
Vegetative Filter Strips	*E. coli*	13	6	N/A	Goel, et al., 2006
Vegetative Filter Strips	fecal coliform	54	6	N/A	Goel, et al., 2006
Vegetative Filter Strips	total coliform	28	6	N/A	Goel, et al., 2006
Vegetative Filter Strips	All2	32	18	N/A	N/A
Wet Basin	coliphage	40	1	15	Gerba et al., 1999
Wet Basin	*Cryptosporidium*	89	1	15	Gerba et al., 1999
Wet Basin	Enterococci	23	1	20	Davies and Bavor., 2000
Wet Basin	fecal coliform	47	4	102	Gerba et al., 1999, Mallin, 2002
Wet Basin	*Giardia* cysts	98	1	15	Gerba et al., 1999
Wet Basin	heterotrophic bacteria	22	1	20	Davies and Bavor., 2000
Wet Basin	thermotolerant coliform	-3	1	20	Davies and Bavor., 2000
Wet Basin	total coliform	62	1	15	Gerba et al., 1999
Wet Basin	All2	47	11	222	N/A
Wetland	*Clostridium*	97	2	N/A	Stenstrom and Carlander, 2001
Wetland	coliphage	86	8	85	de J. Quinonez-Diaz et al., 2001, Gerba et al., 1999, Karpiscak et al., 1996, Stenstrom and Carlander, 2001
Wetland	*Cryptosporidium*	90	6	76	de J. Quinonez-Diaz et al., 2001, Karpiscak et al., 1996
Wetland	*Cryptosporidium* oocysts	64	2	30	Gerba et al., 1999
Wetland	*E. coli*	99	3	N/A	Stenstrom and Carlander, 2001
Wetland	enteric virus	97	5	70	de J. Quinonez-Diaz et al., 2001, Karpiscak et al., 1996
Wetland	Enterococci	85	1	20	Davies and Bavor., 2000
Wetland	fecal coliform	93	23	352	de J. Quinonez-Diaz et al., 2001, Gerba et al., 1999, Khatiwada et al., 1999, Neralla et al., 2000
Wetland	fecal enterococci	100	2	N/A	Stenstrom and Carlander, 2001
Wetland	*Giardia*	93	6	76	de J. Quinonez-Diaz et al., 2001
Wetland	*Giardia* cysts	81	2	30	Gerba et al., 1999
Wetland	heterotrophic bacteria	87	1	20	Davies and Bavor., 2000
Wetland	sulfite reducing anaerobic sporeformers	83	1	N/A	Stenstrom and Carlander, 2001
Wetland	thermotolerant coliform	79	1	20	Davies and Bavor., 2000
Wetland	total coliform	91	19	202	de J. Quinonez-Diaz et al. 2001, Gerba et al., 1999, Neralla et al., 2000, Stenstrom and Carlander, 2001
Wetland	All2	88	82	981	N/A

Notes:

N/A - values are not available for this parameter

Data for Flood Control/Water Quality Basins from previous studies was not found

Negative values reflect increase in concentration between influent and effluent

Studies used for analyses are listed in Appendix I

1 Percent removal was calculated as the average of the percent removals measured at each BMP tested

2 Percent removal for "All" was calculated as the average for all indicators tested

3 Data obtained from the International Stormwater Best Management Practices (BMP) Database at http://www.bmpdatabase.org/

4 From study conducted by the Mississippi Department of Marine Resources -
http://www.dmr.ms.us/CoastalEcology/Storm/APPENDIX-C/Dayton%20Biofilter%20Grass%20Swale.pdf#search='dayton%20biofilter'

2.1.2 Wet Basins

Wet basins, often also referred to as wet ponds and retention basins or ponds, are structural best management practices designed to store stormwater runoff between rainfall events. A large variety of designs fit within the broad designation of wet ponds including aeration basins and amenity ponds and lakes. Wet basin systems are often composed of a series of different types of pools and storage areas each of which is designed to perform a different task to improve water quality. The number and types of these pools varies from basin to basin. These, however, are all designed to store water between runoff events and to discharge water stored from the previous runoff event with influent from the subsequent event. The level of effectiveness may vary greatly depending upon the structural characteristics of these systems and depends greatly upon the ability of the basin to completely discharge before contaminants from the current rain storm are dispersed to the outflow location and, as a result, out from the wet basin.

In the Houston Metro Area, permits have been issued for wet ponds, wet ponds with detention, and 10/100 year wet trash basins. The latter systems incorporate additional structures to the wet basins to increase the utility of the systems. Wet ponds with detention are designed to retain runoff water for an extended period of time to allow additional settling and/or treatment processes to occur. The 10/100 year wet trash basins have additional structures to remove trash and have increased capacity to capture the 10/100 year storm. Although these systems may have different designs, each operates by the definition adopted for this study. Because these systems all function according to the definition for wet pond given previously, this study includes each of these within the broader designation of wet pond.

During the period of time over which the storm water is retained, several processes may significantly impact the population size of bacteria in the wet basin. This highlights the importance of the extended storage time and the importance of preventing short circuiting (or the discharge of volumes of water that have not been retained in the structure for a sufficient period of time for reduction to occur) in the storage volumes. Research studies cite adsorption/settling/ sedimentation, temperature, visible and ultraviolet light, and competition and predation from other microorganisms as the dominant mechanisms for removal (Khatiwada and Polprasert 1999; Davies and Bavor 2000; Darakas 2001; Brookes et al. 2005; Characklis et al. 2005; Gannon et al. 2005). As in dry basins, the storage of storm water allows for these processes to occur and the length of the storage often correlates positively with the amount of reduction achieved.

An important difference between the efficiency of wet basins and dry basins is the different role that aquatic vegetation may play within wet basins. Some basins have vegetation and some are concrete lined. In both wet and dry basins, the presence of vegetation increases the ability of the system to trap sediments and other contaminants flowing into the system and may increase sedimentation through the reduction of velocities; however, vegetation also reduces the penetration of solar radiation that kills bacteria.

Studies performed on the rates of removal of bacteria in wet ponds have obtained wide ranges for efficiencies. These variations are partially the result of design differences but may also be affected by sample collection methodology, wildlife inputs, seasonal variation, and other ambient conditions. Values for the efficiencies of wet ponds and other BMPs are included in Table 3. This table lists removal efficiencies for thermo-tolerant coliforms, Enterococci, heterotrophic bacteria and fecal coliform that were obtained from various studies performed on

BMPs. The efficiencies found for wet ponds range from negative 3.0 percent (net growth) for thermo-tolerant coliform bacteria to over 99 percent removal for fecal coliform bacteria.

Table 4 shows the average efficiency measured for each BMP for all of the indicators tested. One problem discussed in several articles that analyze the results of BMP efficiency studies is the need for consistency in sampling design and analysis of data (Strecker et al. 2001; Barrett 2004). In addition, environmental conditions cannot be controlled in field studies (and may not always be accounted for in lab studies). As a result, factors such as sunlight, temperature, wildlife populations, and wind may have had drastic effects upon the efficiencies for each wet pond but may not always be accounted for. Many of the publications fail to discuss important details of the environmental conditions encountered during the collection of the samples. Several of these studies also monitor the removal of different indicators. The die-off rates for different groups of fecal bacteria in natural environments have been shown to vary (Davis and Valentino 1985; Anderson et al. 2005). In addition, these studies rarely discuss the maintenance and upkeep of the pond systems and poorly-maintained ponds may impede the ability of these to function properly.

Table 4: Average Efficiencies for All Bacteria Types

BMP Tested	Percent Reduction	Total Samples Collected
Dry Basin with Filter	90.0	N/A
Grassy Swale	-338.0	5
Vegetative Filter Strips	31.7	N/A
Wet Basin	47.3	222
Wetland	88.3	981

As shown in Table 1, most of the storm water quality permits for wet basins in the Houston metro area were issued by the City of Houston and Harris County. As of October 2005, the City of Houston (COH) issued 10 permits for wet basins installed within city limits. Harris County (HC) issued sixty active permits for wet basins. Wet basins account for 7 percent of the total number of permits issued for BMPs by these two agencies. A total of 3695 acres of land in the Houston Metro Area drain to permitted wet basins. This is more than that for any BMP type other than dry basins.

2.1.3 Wetlands

As shown in Table 1, only three artificial wetland systems are implemented in the Houston Metro Area. Although the primary function for all of these is not water quality treatment, each system has water quality features. The Harris County Flood Control District (HCFCD) planned the construction each of these systems yet only the Greens Bayou Wetland Mitigation Bank was completed at the time of this report. Planting activities at the two other wetland systems is ongoing. One of these was constructed at Arthur Storey Park located in southwest Houston and the other is a salt marsh located along the downstream portion of Brays Bayou and is meant to treat not only stormwater but also excess flow from Brays. Additional wetlands and wet basins are currently being planned for the Greens Bayou Wetland Mitigation Bank.

Many studies have been performed on the effectiveness of wetland systems. Although these systems are not common in Houston, previous studies have shown high efficiencies for fecal pathogen removal. The focus of the evaluation of these systems for use in the Houston Metro Area will rely primarily upon the results of previous studies. These can be natural or constructed systems and both types encompass a wide range of layouts. Wetland systems share many of the primary removal mechanisms that are utilized by both wet ponds and dry ponds. Wetlands allow settling/sedimentation of contaminants, bacterial decay from solar radiation, temperature, and predation/competition (Khatiwada and Polprasert 1999; Davies and Bavor 2000). Wetland systems also increase the potential for filtration of contaminants and the uptake of nutrients predominantly due to the increased presence and role of vegetation (Gerba et al. 1999; JTF 2001a). Substantial reductions (de J. Quinonez-Diaz found reductions of around 90%) of microorganism concentrations from untreated domestic wastewater has been detected using wetlands with only a one to two day detention time (Neralla et al. 2000; De J. Quinonez-Diaz et al. 2001). The period of retention for most wetland systems, however, exceeds this one to two day minimum and the level of reduction has been shown to increase as the treatment time increases (Khatiwada and Polprasert 1999).

As with wet pond systems, the data for the removal of bacteria in wetlands are highly variable. Studies commonly provide ranges for bacterial reduction from wetlands of 70% to 99%; however a study conducted in Fremont, CA showed a net increase of 134% (Neralla et al. 2000; Stinson and Perdek 2004). The deposition of fecal material by wildlife may be an additional large source of fecal bacteria in wetlands (Stenstrom and Carlander 2001). Wetlands often function as habitats for a wide range of animals. Values for wetland efficiencies found in several studies performed on wetlands and other BMPs are shown in Table 3.

Several studies have been completed to test the effect that different factors have upon the bacterial removal efficiencies of wetlands. A study conducted by Khatiwada and Polprasert (1999) found that fecal coliform removal varied with the rate of hydraulic loading of contaminated water. A study conducted by Davies and Bavor (2000) found removal efficiencies for a wetland in Australia of 79, 85, and 87% for thermo-tolerant, Enterococci, and heterotrophic bacteria respectively. Their study also found that inflow and outflow concentrations of Enterococci and outflow concentrations of thermo-tolerant coliforms and heterotrophic bacteria correlated significantly with total daily rainfall.

In wetlands, vegetation plays a much more important role than in wet ponds. Gerba, et al. (1999) studied the removal of five indicator microorganisms in two types of wetlands in Arizona. Between 58 and 99% removal of fecal and total coliforms was measured and both types of wetlands showed reductions in the concentrations of all the indicators tested. The authors found that although settling may have played a significant role in bacteria removal, "increased physical contact of pathogens with plant roots and wetland substrate may be the primary mechanics of pathogen removal".

Studies on the effect of other variables upon bacteria removal have provided conflicting results. Gerba, et al. (1999) found no correlation between temperature, pH, and turbidity and the removal of fecal indicator bacteria in two wetland systems that were tested. A study performed at the same lab in Tucson, Arizona, however, found that water temperature was "the most important factor in the removal of enteric bacteria and viruses, while turbidity reduction was related to *Giardia* removal" (De J. Quinonez-Diaz et al. 2001). Kadlec and Knight (1996) found that wetlands have a residual fecal pathogen indicator population and that in wetlands that have low influent indicator concentrations, the effluent concentrations increase due to the input from the native populations. For relatively high inflow concentrations, however, the wetland system will act efficiently to remove a large percentage of the bacteria.

In wetlands, vegetation fulfills several key roles in the removal of fecal pathogens from storm water. Bledsoe (2001) lists six important factors due to the presence of vegetation that affect water quality in storm water runoff: First, vegetation absorbs some of the impact of rainfall on soil; second, the "root systems physically restrain soil particles"; third, vegetation reduces the velocity of runoff, increasing the potential for settling of pollutants; fourth, "plants dampen turbulence and reduce instantaneous shear stresses" reducing the potential for erosion and transport of pollutants; fifth, roots and humus increase the potential for infiltration, reducing runoff volumes; finally, transpiration reduces the potential for water-logging.

It is difficult to measure the benefits that vegetation provides without measuring the differences for each region before and after a system has been implemented. Without this capability, an understanding of each of the pathways involved must be developed. From this, the benefit of vegetation for each practice may be determined. The results of a study performed by De J. Quinonez-Diaz et al. (2001) showed greater reductions for total coliforms, fecal coliforms, enteric viruses, and coliphages in unplanted wetland systems than in wetland systems with planted bulrush. The reductions for both systems, however, remained above 86% and varied by only about 5% or less between the two types. Vegetation increases sedimentation by decreasing velocities but also decreases the temperatures and the removal through exposure to UV radiation (Khatiwada and Polprasert 1999).

In the Houston Metro Area there are very few man-made wetland systems and even fewer wetlands that have been designed for water quality purposes. Several of the constructed wetland systems were implemented to replace wetland systems that have been destroyed. Previous studies have found relatively high removal rates for wetland systems, as shown in Tables 3 and 4, and, as a result, it is considered important to gain additional data on the efficacy of wetlands in the Houston area.

2.1.4 Vegetative Filter Strips

Vegetative filter strips are landscaped grassy regions that can be implemented adjacent to a source of pollutants when the main transport pathway from the source is sheet flow. The main reduction pathways are trapping and filtration of bacteria from sheet flow and increasing the contact of vegetation to the runoff increases the efficiency of these BMPs. In addition, Goel et al. (2004) noted that runoff volumes were reduced during passage through vegetative filter strips and that efficiency is directly related to the length of the filter strip. Plants chosen for these controls that have shown the potential to filter bacteria include Buffalo grass, Meadow sedge, Cherokee sedge, and Blue eyed grass (JTF 2001a).

Studies have shown mixed results for bacteria removal from the passage through vegetative filter strips. Goel et al. (2004) found that different types of vegetation provided different bacterial trapping efficiencies and that the rates of trapping were highly variable. The average trapping efficiencies from this study were all positive and ranged from 15% to 95% depending on the type of vegetation and the fecal pathogen indicator tested; however, several trials produced net pathogen increases. Some studies point to the usefulness of these systems to help the efficiency of multi BMP systems (JTF 2001a; Goel et al. 2004). Until more is understood about the designs and effects of these systems, however, the lack of proven removal capabilities indicates that they should not be used independent of other management methods.

The dominant soil types in the Houston metropolitan area belong to group D. These soils are high in clays and do not allow much infiltration. This limits the ability to use vegetative filter strips for runoff volume reduction in Houston. There are small portions of Harris County with annual infiltration rates of up to 14 inches per year. In those areas, this is an additional pathway by which the effectiveness of filter strips should be evaluated.

2.1.5 Grass Swales

Grass swales are earthen channels that are lined with plants with the intent of trapping contaminants in the water passing through. As in vegetative filter strips, these systems depend primarily on the ability of vegetation to trap and filter out contaminants. This process is heavily dependant upon the type of vegetation, the maintenance of the structure, and the hydraulic properties of the structure (Goel et al., 2004; JTF 2001a). The JTF recommends several types of plants to be used when planting grass swales in "Minimum Design Criteria-Runoff Treatment BMP" (2001). These plants exhibit the ability to filter contaminants from runoff. Several hydraulic properties for the flow through the system are required, however, to take full advantage of the potential of the vegetation. The runoff should pass through the system with the greatest possible contact to the planted vegetation. Thus the JTF recommends that the grass swale be designed to promote sheet flow with a height of less than 3 inches or half the height of the vegetation. In addition, any accumulated sediments may prevent optimal contact with vegetation and could provide a source of fecal pathogens to the runoff, creating the potential for greater concentrations of the pathogens in the outflow than in the inflow.

As in vegetative filter strips, the grass swales can also be used to promote the infiltration of runoff volumes and thus reduce the volumes of water that discharge to the receiving body of water. As discussed previously, the majority of soil types in the Houston area do not exhibit high rates of infiltration; however, when developing a BMP implementation plan for any region, this is a factor that should be considered. Because of the similarity of the processes involved in vegetative filter strips and grass swales, these controls should be used to take advantage of site properties.

2.2 STORMWATER IN THE HOUSTON METRO AREA

Four agencies that maintain the Municipal Storm Sewer System (MS4) for the Houston Metropolitan Region joined together to develop the stormwater management plan (SWMP) for the area. The City of Houston (COH), Harris County, the Harris County Flood Control District (HCFCD), and the Texas Department of Transportation (TxDOT) formed the Stormwater Management Joint Task Force (JTF) and work together to manage storm water and associated pollutants that are discharged from the MS4 to Texas water bodies. The JTF obtained a National Pollutant Discharge Elimination System (NPDES) permit from the TCEQ and under the guidelines of the MS4 permit, the JTF has the authority to grant permits for the implementation of BMPs in the region (JTF 2001b). The JTF has implemented additional BMPs as described in the SWMP and releases annual reports on the progress of meeting the goals of the plan.

Many of the BMPs implemented in the Houston area were designed to mitigate the impacts of commercial and residential development and industrial facilities. Phase two of the NPDES permitting program required that these facilities submit a Storm Water Pollution Prevention Plan (SWP3) and obtain a permit for any discharges to the MS4 or regulated water bodies. Temporary BMPs are implemented during construction and permanent BMPs are constructed to attempt to maintain discharges at the same rate, quantity, and quality as existed during pre-development conditions. Initially, BMPs were implemented primarily for flood control; however, many of the same BMPs are being implemented to reduce the concentrations of contaminants in storm water runoff.

The JTF developed minimum design criteria to improve the effectiveness of these systems. The "Storm Water Quality Management Guidance Manual" and the "Minimum Design Criteria for Implementation of Certain Best Management Practices for Storm Water Runoff Treatment Options" provide maintainance information, formulas to design the BMPs, and examples of effective BMP designs (JTF 2001a). These guidelines and criteria were reviewed in this project, incorporated into the site selection strategy, and will be seen later in this report.

CHAPTER 3

DATABASE DEVELOPMENT

To understand the effect that different BMP implementation scenarios would have in the Buffalo and Whiteoak Bayou watersheds and throughout the rest of the Houston Metro region, it is crucial to understand the current status of BMPs in the region. The objective of Task 3 of the work order for this project is to develop a database of the quantity and type of BMPs currently in use in the Houston-Harris County Area. Much of the data for the City of Houston were compiled by a group at the University of Houston (UH) for a project initiated by the Harris County Flood Control District. The majority of data for BMPs in Harris County were obtained from the Harris County Public Infrastructure Department and the UH group.

Table 1 contains a list of the types of BMPs and the number of each type that have been permitted in the Houston area and the agency that issued the permit. Harris County and the City of Houston have issued the majority of the permits for commercial and residential development and industrial facilities. Table 2 shows the drainage areas for each type and the total volumes of runoff that these facilities are able to hold. The locations of BMPs with active permits for the Houston metro area are shown in Figures 1 and 2. Additional BMPs have been installed by the JTF in accordance with the requirements of the SWMP. Dry ponds with detention basins are the most numerous of the BMPs permitted by Harris County. As discussed previously, these are less expensive and require less maintenance than wet basins and wetlands, but have the capacity to

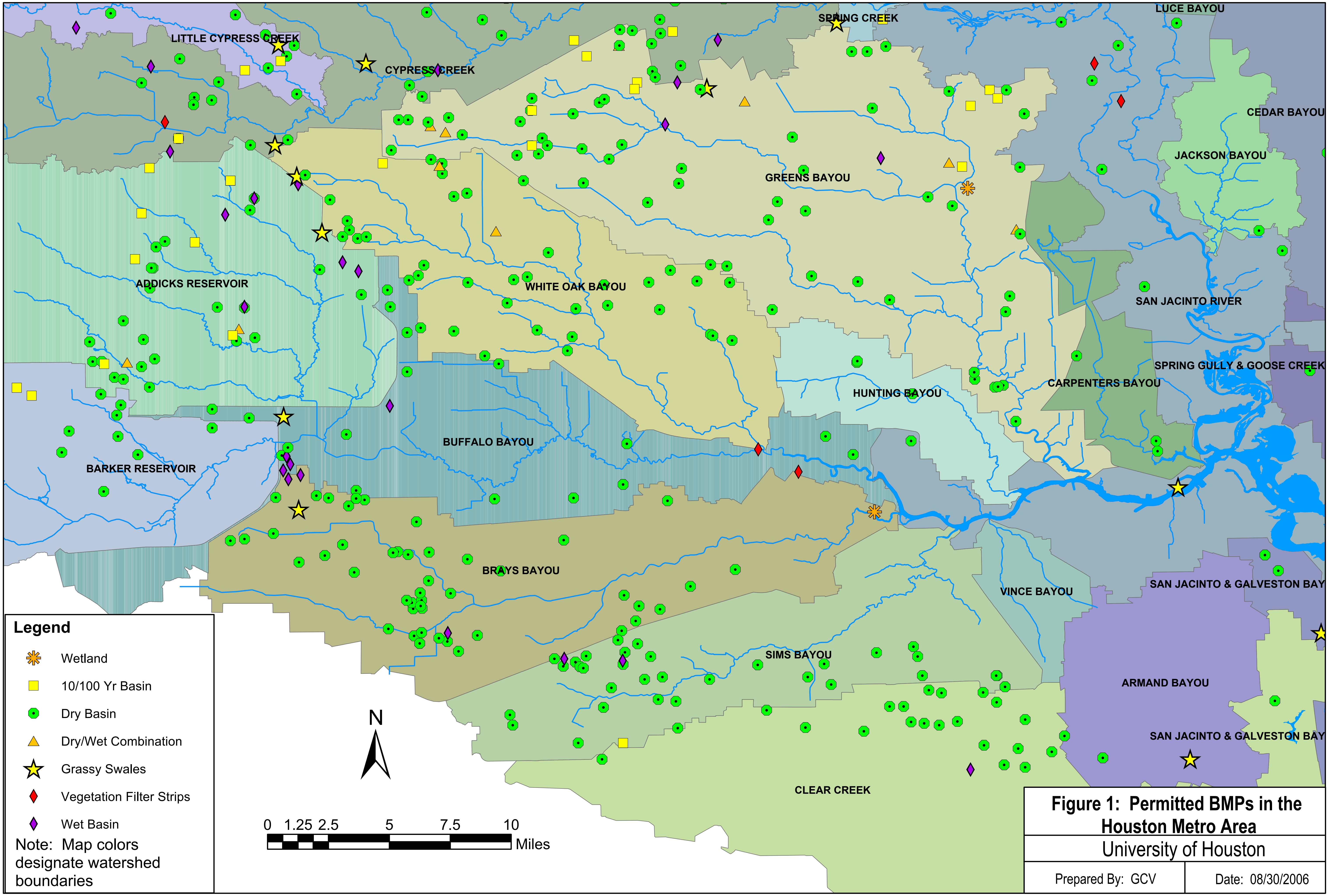


Figure 1: Permitted BMPs in the Houston Metro Area

hold greater volumes of water than the grassy swales and vegetative filter strips. Wet basins (also known as wet ponds) are less frequently implemented. A total of 70 wet basins were permitted by the JTF (60 in Harris County and 10 in the City of Houston). The wet basins detain a permanent pool of water from each runoff event that is displaced by runoff from the subsequent runoff event. Many other types of BMPs including combination basins (also known as dual use and flood control/water quality basins), street sweeping, vegetative filter strips, and grass swales are currently used and may have an important effect on the bacterial concentrations of storm water runoff entering Texas surface water bodies in Houston. Oil/Grit/Trash (OGT) separators are the second most numerous type of BMPs in use in the region. The JTF reports that these have less of an effect upon the bacteria concentrations of receiving water bodies (JTF 2001a; JTF 2001b). This study will include an analysis of OGT systems, including historical data and study results, but does not include sampling for these.

An electronic version of the BMP database is included in Appendix B.

CHAPTER 4

SITE SELECTION AND RECONNAISSANCE

Sites for sample collection were chosen to determine the effectiveness of the BMPs permitted in the Houston Area and to address several questions necessary to develop an implementation plan for the region. To gather data on the types and designs of the systems that are implemented in the Houston area, the stormwater management plans (SWMPs), the stormwater pollution prevention plans (SWP3s), and other permit documents such as the site plans were obtained. Using these data, sites were rated according to the desired properties for each type of BMP. The next step undertaken was reconnaissance of the highest rated sites. The reconnaissance process addressed several important goals. First, monitoring of BMP sites can be a very difficult task for several reasons. Sites had to be evaluated not only on design factors but also on the success of the implementation of the structure. The maintenance, stabilization, and other factors relevant to the effectiveness of these systems cannot be determined from the permit documents. In addition, access to many of the sites and the sample collection locations at each site can be restricted or difficult

4.1 SELECTION OF SITES FOR SAMPLE COLLECTION

Based on information from several different sources, including the Harris County Public Infrastructure Department, the Harris County Flood Control District, and a study currently being conducted at the University of Houston to determine the effectiveness of different detention pond designs for reducing the nutrient concentrations from storm water runoff, data were gathered on the designs of BMPs in the Houston metro area. To choose sites for reconnaissance, a list of the permitted BMPs located within several watersheds of interest was created. The list includes the Addicks and Barker Reservoirs, Brays Bayou, Buffalo Bayou, Sims Bayou, and White Oak Bayou. Next, if a large number of BMPs were permitted in the region for a particular type, the BMPs were ranked according to specific design parameters. The parameters chosen and calculations for site selection are shown in Table 5; these variables are specified by the JTF as fundamental to the effectiveness of each type of BMP for contaminant removal.

4.1.1 Dry Basins

The primary mechanisms of contaminant removal in detention basins are sedimentation, detention time, and discharge rate. As a result, the detention basins permitted for Harris County and the City of Houston were ranked according to the design characteristics that control these processes. The water quality storage volume, drainage area, pond geometry, outlet design, stabilization, and the maintenance of each site were analyzed. In addition, to satisfy the requirements of sample collection, the access to the site and the safety of each sample collection location were addressed. For each of the categories, a scoring system was established. The scores for each category at each system were summed to calculate a total score between 0 and 15 and the structures were ranked according to this score (Table 6).

Table 5: Score Calculations

Variable Name	Calculation	Score Formula	Score Range
Water Quality Ratio	=(Water Quality Volume) / (Regulated Volume)	IF RATIO>4 THEN = 1 OR IF RATIO>2 THEN ((VALUE-2)*0.05)+0.85 OR IF RATIO<=2 THEN VALUE*0.425	0-2
Length/Width Ratio	= Length of Basin/Width of Basin	IF RATIO>20 THEN = 1 OR IF RATIO>6 THEN =((RATIO-6)*0.007143) + 0.9 OR IF RATIO>3 THEN =((RATIO-3)*0.0333) + 0.8 OR IF RATIO<=3 THEN =RATIO*0.2667	0-1
Least Distance	=(Distance Between Inlet and Outlet) / (Greatest Length Possible in Basin)	IF RATIO IS > 0.8 THEN = 3 OR IF NOT THEN = RATIO*3.75	0-3
Number of Inlets and Outlets	= Number of Inlets + Number of Outlets	(6-VALUE)*1.25	0-5
Maintanence/Implementation	N/A*	N/A*	0-3
Access	N/A**	N/A**	0-2

Notes:
* Evaluated during site inspections, scores determined by outlet design, site stabilization, accumulated sediments, and maintenance
** Evaluated during site inspections, scores determined by safety and accessibility

The first category used to rank dry basins for sample collection was the water quality volume ratio. The JTF requires that the water quality storage volume of a detention basin be large enough to hold a minimum of 0.5 inch of runoff from the drainage area. The water quality volume ratio is the ratio of the implemented water quality volume to the water quality volume required by the JTF. Larger water quality volume ratios were assigned higher scores.

The second and third categories describe the length of the detention period for each basin. The second category calculated was the ratio of the length to the width of the basins. The ratio of these two values describes the ability of the basin to function similar to a plug flow reactor. This is the ideal scenario that would guarantee the greatest length of time for treatment of all detained water and prevent short circuiting. The third category was the distance between the inlet(s) and the outlet(s). As the distance between these locations increases, the detention time of the system also increases. Larger values for each of these categories were given higher scores.

During each runoff event monitored, the number of samples collected will increase the statistical significance of the results. In addition, the number of samples will help provide a clearer picture of the changes in bacteria concentrations through time. As a result, it is very important to limit the number of inlets and outlets at each sample collection location and scores were calculated for each system according to the number of inlets and outlets. The highest scores were given to basins with the fewest total number (one inlet and one outlet).

Proper implementation and maintenance of the detention basins is very important to ensure that each is effective. During site inspections, grades were given to each basin to describe four important variables: the outlet design, site stabilization, amount of accumulated sediments, and the maintenance of the vegetation in the basin. The maintenance score was calculated as the sum of the scores for each of these variables.

The sixth category by which detention basins were ranked is the accessibility of the basin, in addition to that of the inlets and the outlets. Similar to the score determined for maintenance, sites were given points for three variables: safety of accessing sample collection locations, access to the site, and the presence of a gate or other obstruction.

Detention basins represent a large percentage of the BMPs that have been implemented in the Houston metropolitan region. As a result, a large number of detention basins were visited. These site visits helped create a more complete understanding of the status of these BMPs and the effectiveness that detention basins may have on bacteria concentrations in storm water runoff. In addition, this process helped determine detention basins designs that are common to the region and the data necessary to help address the goals of this study. Additional factors were considered in the ranking process as discussed below.

The rankings of all of the permitted detention basins are shown in Table 6. Two detention basins were chosen for sample collection: the detention basin located at Alief ISD Intermediate School Number 6 and permitted under City of Houston Stormwater Permit Number 2002-062 and the detention basin located at Alief ISD Elementary School No. 23 and permitted under City of Houston Stormwater Permit Number 2004-027. These two systems were located close to each other, minimizing travel time and maximizing sample quantities. They also offered different design characteristics and, as a result, alternative approaches to detention basin effectiveness could be tested.

The detention basin approved under permit number 2002-0062 (DB1) ranked as the higher of the two designs primarily on the strength of maintenance and the outlet structure design. The outlet structure chosen for that detention basin ensures a longer period of detention than is seen in many of the detention basins. In addition to potential water quality benefits, this allows for

Table 6: Scores for Dry Basin Design Parameters

PermitNo	Project	Total Score	Receiving Water	Sampling Site	# Inlets	Shortest Distance	L/W Ratio	WQ Vol Ratio	Access	Maint.
8-0000304-7	Lakes of Bellaire, Sec. 3 & 4	14.59	Brays Bayou	N/A	1	0.8	4.5	2.40	N/A	N/A
8-0000042-1	Kingsland Park & Ride Expansion	13.63	Barker Reservoir	DB Alt 5	1	0.7	3	1.42	5	5
8-0000009-1	N/A	13.63	Addicks Reservoir	N/A	1	0.7	4	2.71	5	4
2003-0031-R04	Moorings Apartments	13.44	Brays Bayou	WB Alt 4	1	0.8	3	N/A	5	3
8-0000169-8	Oak Landing - Sec 1	13.08	Addicks Reservoir	DB Alt 6	1	0.8	4	1.00	5	4
2002-0062-R04	Alief ISD Intermediate School No. 6	13.06	Brays Bayou	DB 2	1	0.55	1.5	N/A	4	5
8-0000042-1	Kingsland Park & Ride Expansion	13.03	Barker Reservoir	DB Alt 5	1	0.7	3	1.42	5	5
8-0000221-6	Copper Village - Sec. 9	12.76	Addicks Reservoir	N/A	1	0.65	2	2.89	4	4
2004-0008-R05	West Belfort Park and Ride Expansion	12.38	Brays Bayou	N/A	1	1.23	2.92	N/A	5	1
2004-0027	Alief ISD. Elementary School No. 23	12.33	Brays Bayou	DB 1	1	0.58	1.14	N/A	5	5
2002-0228-R03/04	Westchase Park and Ride Facility	12.32	Brays Bayou	DB Alt 3	1	0.5	6	N/A	5	5
2002-0228-R03/04	Westchase Park and Ride Facility	12.32	Brays Bayou	GS Alt 1	1	0.5	6	N/A	5	5
2003-0129-R04	Hilton Garden Inn & Future Development	11.87	Brays Bayou	N/A	1	0.65	4	N/A	5	1
2003-0117-A04	Southwest Beltway Business Park	11.64	Brays Bayou	AltGeneral	1	0.5	1.37	N/A	4	3
2003-0098-R04	Westway Park Detention Modification	11.58	White Oak Bayou	AltGeneral	2	0.6	9.7	N/A	4	4
2005-0079	Park At Clearview	11.22	Brays Bayou	N/A	1	0.29	2	N/A	3	4
2003-0062-RA04	Men's Wearhouse BVDC Trailer Parking Expansion	11.14	Brays Bayou	N/A	1	0.8	4.25	N/A	2	2
8-0000152-3	Cypress Meadow - Sec. 5 & 6	10.88	Addicks Reservoir	N/A	1	0.4	2	1.00	4	4
8-0000176-0	Eagle Ranch West	10.54	Addicks Reservoir	N/A	2	0.66	5	0.94	4	3
8-0000065-6	Saint Edith Stein Catholic Community	10.53	Addicks Reservoir	N/A	1	0.3	3	31.48	5	1
8-0000227-0	Gardens at Westgreen	10.41	Barker Reservoir	N/A	1	0.7	2	1.00	3	2
2003-0061-R04	Men's Warehouse BVDC Exp.	10.40	Brays Bayou	N/A	1	0.7	9	N/A	2	2
2004-0040	Saigon Houston Plaza Reserve"A" & "B"	10.33	Brays Bayou	N/A	1	0.9	11.36	N/A	N/A	2
2002-0220	Men's Wearhouse BVDC Trailer Park Expansion	9.79	Brays Bayou	N/A	1	0.5	5	N/A	2	2
2002-0186	Sunrise at South Gessner	9.46	Brays Bayou	N/A	1	0.7	4	N/A	N/A	N/A
2003-0105	Ho Ho Ho Express, Inc.	9.45	Addicks Reservoir	N/A	1	0.71	12.1	N/A		
2002-0229- R04,05	A.C.P.I. (Asia Chemical Corp.., Inc.)	9.43	Buffalo Bayou	N/A	1	0.7	3	1.24	N/A	N/A
2002-0153-R03,04	Eldrige Apartments	9.34	Buffalo Bayou	N/A	1	0.7	44	N/A	N/A	N/A
2004-0048	River Oaks Baptist Church and School	9.33	Buffalo Bayou	N/A	1	0.75	3.46	N/A	N/A	N/A
2004-0058	Phoenicia Specialty Foods Development	9.22	Brays Bayou	N/A	1	0.05	4	N/A	4	1
2003-0001-R04	Pine Vista Business Park	9.21	White Oak Bayou	N/A	1	0.6	15	N/A	N/A	N/A
2002-0235	Family Dollar Store	8.94	White Oak Bayou	N/A	1	0.63	2.18	N/A	N/A	N/A
2004-0110	West Houston Medical Office Building	8.89	Brays Bayou	N/A	1	0.82	5.85	N/A	N/A	N/A
2003-0067-R04	3550 Willowbend	8.70	Brays Bayou	N/A	1	0.31	1.25	1.44	3	N/A
2002-0166	Victory Shepard Northwest	8.66	White Oak Bayou	N/A	1	0.8	4	N/A	N/A	N/A
8-0000051-8	Innova Electronics, Inc,	8.64	White Oak Bayou	N/A	1	0.8	3	0.99	N/A	N/A
8-0000088-1	Allsafe Storage	8.48	White Oak Bayou	N/A	1	0.42	7	19.38	N/A	N/A
2005-0080	John Eagle Acura	8.42	Buffalo Bayou	N/A	1	0.41	21	2.75	N/A	N/A
2004-0004	HISD South District Pre-K Center	8.41	Brays Bayou	N/A	1	0.52	1.71	N/A	N/A	N/A
2004-0045	Emnora Heights Subdivision	8.37	Buffalo Bayou	N/A	2	0.68	3.5	N/A	N/A	N/A
2003-0087-R04	Superbag Operating, Ltd	8.25	Buffalo Bayou	N/A	2	0.65	3.5	N/A	N/A	N/A
8-0000204-5	290 Commons (Reserves of)	8.24	White Oak Bayou	N/A	2	0.7	2.3	16.49	N/A	N/A
8-0000242-6	Fairview Business Park	8.09	White Oak Bayou	N/A	1	0.7	2.5	0.94	N/A	N/A
8-0000171-9	Brazos Self Storage	8.07	Addicks Reservoir	N/A	1	0.68	2.5	1.00	N/A	N/A
2005-0046	Midwest Tile	7.99	White Oak Bayou	N/A	2	0.56	5.57	N/A	N/A	N/A
2005-0029	Westheimer Plaza at Briarwest	7.97	Brays Bayou	N/A	1	0.32	2.87	N/A	N/A	N/A
2005-0096	Panther Oaks Subdivision	7.93	Addicks Reservoir	N/A	1	0.3	3	N/A	N/A	N/A
2002-0167-R-03/04	Frito-Lay Houston Distribution Center	7.93	Brays Bayou	N/A	1	0.3	3	N/A	N/A	N/A
2002-0218, Revoked	Sunrise at Emnora	7.90	White Oak Bayou	N/A	1	0.33	2.5	N/A	N/A	N/A
2002-0233-R04,05	HEB - Houston Retail Support Center South Gate Entrance	7.77	White Oak Bayou	N/A	1	0.25	4	1.95	N/A	N/A
8-0000366-5	Clayton Park Detention Basin	7.75	Buffalo Bayou	N/A	1	0.65	1.75	1.00	N/A	N/A
8-0000047-3	Windfern Subdivision	7.74	White Oak Bayou	N/A	1	0.53	6	1.00	N/A	N/A
8-0000318-5	Bridgewater Meadow Detention Basin	7.69	Barker Reservoir	N/A	1	0.65	1.5	1.00	N/A	N/A
2005-0036	Airline Plaza	7.68	White Oak Bayou	N/A	1	0.54	3	N/A	N/A	N/A
2004-0059	Men's Wearhouse BVDC Phase III	7.66	Brays Bayou	N/A	1	0.7	1.5	N/A	N/A	N/A
2003-0005-R04	William Marsh Rice University	7.63	Brays Bayou	N/A	1	0.6	2	N/A	N/A	N/A
8-0000269-0	8 Center Industrial Park	7.63	Buffalo Bayou	N/A	1	0.5	8	0.99	N/A	N/A
2004-0077	Harris County Youth Service Center	7.61	Brays Bayou	N/A	1	0.72	7.33	N/A	N/A	N/A
8-0000271-1	Pinnacle Apartments	7.53	White Oak Bayou	N/A	1	0.6	1.6	1.00	N/A	N/A
2003-0170	The Parish School Phase I	7.52	Buffalo Bayou	N/A	2	0.8	3	N/A	N/A	N/A
8-0000417-6	Houston Garden Center Store No. 20	7.42	Addicks Reservoir	N/A	1	0.5	2.5	1.03	N/A	N/A
2003-0021	Sunrise at Tidwell	7.36	White Oak Bayou	N/A	1	0.36	4	N/A	N/A	N/A
2003-0035-R04	Momentum Porsche Audi	7.33	Brays Bayou	N/A	1	0.55	1.6	N/A	N/A	N/A
2004-0096	HISD Phillis Wheatly High School	7.28	Buffalo Bayou	N/A	1	0.66	1.5	N/A	N/A	N/A
8-0000005-2	Millestone Apartments	7.28	Barker Reservoir	N/A	2	0.7	3	1.01	N/A	N/A
2004-0010-R05	Fairbanks Business Park, LTD	7.28	White Oak Bayou	N/A	1	0.66	3	N/A	N/A	N/A
8-0000332-9	Northwest Eight Business Center (aka XL Parts Distribution)	7.22	White Oak Bayou	N/A	2	0.5	1.3	13.25	N/A	N/A

Table 6: Scores for Dry Basin Design Parameters

PermitNo	Project	Total Score	Receiving Water	Sampling Site	# Inlets	Shortest Distance	L/W Ratio	WQ Vol Ratio	Access	Maint.
2003-0131-R04	Debur Building	7.22	White Oak Bayou	N/A	1	0.54	1.3	N/A	N/A	N/A
2003-0097	Northwest Place Estates	7.07	White Oak Bayou	N/A	2	0.3	12.9	N/A	N/A	N/A
8-0000046-0	N/A	7.00	Addicks Reservoir	N/A	2	0.6	6	1.00	N/A	N/A
8-0000367-8	Westgreen Business Center (aka Westgreen Business Park)	6.90	Barker Reservoir	N/A	2	0.4	1.5	22.18	N/A	N/A
2005-0076	Rosemont at Northline Apartments	6.85	White Oak Bayou	N/A	3	0.51	11	N/A	N/A	N/A
2004-0068	Little York Villas Apartments	6.83	White Oak Bayou	N/A	2	0.27	3.58	N/A	N/A	N/A
2002-0165-R04	Sercel, Inc.	6.73	Buffalo Bayou	N/A	2	0.3	6	N/A	N/A	N/A
8-0000068-3	Tanner Freeport Business Park	6.42	White Oak Bayou	N/A	2	0.2	2.5	17.99	N/A	N/A
2004-0085	Houston Cardiac Association	6.36	Brays Bayou	N/A	1	0.31	1.32	N/A	N/A	N/A
2002-0043-R03/04	Universal Compression, Inc	6.31	Buffalo Bayou	N/A	1	0.2	2.5	N/A	N/A	N/A
8-0000100-3	N/A	6.24	White Oak Bayou	N/A	2	0.1	5	8.42	N/A	N/A
8-0000335-6	Barker Village Section 1 and future 9.58 acres	6.16	Addicks Reservoir	N/A	1	0.3	0.7	1.00	N/A	N/A
8-0000353-9	Ferndale Subdivision	6.16	White Oak Bayou	N/A	2	0.1	9	3.65	N/A	N/A
2005-0041	Highland Heights Elementary School	6.14	White Oak Bayou	N/A	3	0.5	1	N/A	N/A	N/A
8-0000092-6	Katy ISD Elementary # 26	6.14	Addicks Reservoir	N/A	2	0.4	3	0.99	N/A	N/A
2002-0045	Enclave By Texas Casador Subdivision	6.06	White Oak Bayou	N/A	1	0.2	2	N/A	N/A	N/A
8-0000352-7	Pavecon Houston Windfern Complex (aka North Houston Gardens)	6.05	White Oak Bayou	N/A	2	0.5	1.2	1.00	N/A	N/A
2005-0075	Westheimer Towne Center	6.02	Buffalo Bayou	N/A	2	0.1	2.4	N/A	N/A	N/A
2004-0035	Stratford High School Additions and Renovations	5.95	Buffalo Bayou	N/A	2	0.56	3.5	N/A	N/A	N/A
2003-0154	New Nursing Home	5.78	White Oak Bayou	N/A	2	0.35	2.33	N/A	N/A	N/A
8-0000202-0	Sunset Meadows - Sec. 1	5.66	Addicks Reservoir	N/A	2	0.3	3	0.86	N/A	N/A
2003-0086-R04	St Stephen Baptist Church	5.65	White Oak Bayou	N/A	1	N/A	3	N/A	N/A	N/A
2004-0018	Kipp Academy - Middle School	5.60	Brays Bayou	N/A	N/A	N/A	N/A	7.91	3	4
2002-0215	Sunrise at Antoine	5.35	White Oak Bayou	N/A	4	0.4	16	N/A	N/A	N/A
8-0000124-1	N/A	5.34	Barker Reservoir	N/A	2	0.25	1.5	1.18	N/A	N/A
2005-0047	Terraces on Memorial	5.21	Buffalo Bayou	N/A	2	0.12	7	N/A	N/A	N/A
2004-0094	Durkee/Northline Relief School	5.19	White Oak Bayou	N/A	3	0.33	6.25	N/A	N/A	N/A
2004-0006	Erickson Retirement Community Marketing Center	5.10	Buffalo Bayou	N/A	2	0.23	1.6	N/A	N/A	N/A
8-0000004-0	N/A	5.00	Addicks Reservoir	N/A	2		N/A	10.94	N/A	N/A
2005-0073	Walmart Expansion # 2257-02	4.98	White Oak Bayou	N/A	3	0.1	2.28	N/A	N/A	N/A
8-0000184-5	Remington Grove - Sec. 1 (Offsite Pond)	4.75	Addicks Reservoir	N/A	4	0.2	20	10.06	N/A	N/A
8-0000297-3	Anson Flowline Equipment (aka 2.9 Acres of … on Sacreson Harms Rd.)	4.62	White Oak Bayou	N/A	2		3	0.97	N/A	N/A
8-0000069-5	Windfern Park	4.58	White Oak Bayou	N/A	3	0.3	2	1.08	N/A	N/A
8-0000191-7	Academy - Mason Rd. & Franz Rd. (Additional Parking)	4.51	Barker Reservoir	N/A	3	0.2	8	1.00	N/A	N/A
8-0000139-1	N/A	4.40	Addicks Reservoir	N/A	1		1.5	N/A	N/A	N/A
8-0000165-9	Time Warner Cable District Office	3.02	Addicks Reservoir	N/A	4	0.08	5.5	0.99	N/A	N/A
2004-0099	St. George Place Elementary School	2.73	Buffalo Bayou	N/A	4	0.1	1.75	N/A	N/A	N/A
8-0000414-9	Brays Bayou Sub-Regional Detention Pond	2.25	Brays Bayou	N/A	N/A	0.6	N/A	N/A	N/A	N/A
2001-0015-R03/04/05/A05	Prologis @ 4501 Blalock	2.00	White Oak Bayou	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8-0000244-1	Cy-Fair (Eldridge) Transportation & Agricultural Facility - Package "A"	2.00	White Oak Bayou	N/A	N/A	N/A	N/A	15.60	N/A	N/A
8-0000246-5	Westfield Terra Section 7	0.85	Addicks Reservoir	N/A	N/A	N/A	N/A	1.00	N/A	N/A
8-0000285-9	ADI Equipment Rental	0.85	White Oak Bayou	N/A	N/A	N/A	N/A	1.00	N/A	N/A
8-0000050-5	N/A	0.85	White Oak Bayou	N/A	N/A	N/A	N/A	1.00	N/A	N/A
8-0000007-7	N/A	0.61	White Oak Bayou	N/A	N/A	N/A	2.28	N/A	N/A	N/A
2004-0077-A04	N/A	0.00	Brays Bayou	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8-0000196-8	Canyon Lakes at Stonegate, Sec. 10	0.00	Addicks Reservoir	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8-0000415-1	N/A	0.00	White Oak Bayou	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8-0000392-3	Laural Point Apts	0.00	Brays Bayou	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8-0000268-8	Westheimer Place - Sec. 3	0.00	Brays Bayou	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8-0000376-4	Highland Creek Ranch Detention	0.00	Addicks Reservoir	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8-0000045-8	N/A	0.00	Addicks Reservoir	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8-0000008-9	Katy ISD Junior High # 9	0.00	Addicks Reservoir	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8-0000372-5	N/A	0.00	White Oak Bayou	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8-0000085-4	Church of the Holy Apostles	0.00	Barker Reservoir	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8-0000400-0	Epiphany of the Lord Catholic Church	0.00	Barker Reservoir	N/A	N/A	N/A	N/A	N/A	N/A	N/A
8-0000263-6	Holy Covenant Un. Methodist Church	0.00	Addicks Reservoir	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Notes:
N/A - Data not available
See Table 5 for explanation of total score
Selected dry basin sample collection sites are highlighted

extended monitoring of the changes in the concentration of bacteria in the detention pool over time. The basin is very well stabilized by vegetation and has been well maintained. These characteristics prevent the resuspension of sediment stored in the basin from previous runoff events. There was a small amount of sediment that had been accumulated within the detention basin but compared to the other basins visited, this was very minimal. This is an important consideration because of the high concentrations of bacteria often found adsorbed to sediments and the potential for resuspension.

The detention basin approved under permit number 2004-0027 (DB2) also ranked very high compared to the other detention basins in Houston. This design was very common so that sampling will be relevant to a large number of the detention basins that have been implemented. In addition, this detention basin is located close to DB2. This was considered an important characteristic because of the fluctuations that are believed to occur in inflow and outflow concentrations over time especially during a runoff event. During each rain event, two BMP sites will be evaluated and it is important to collect several samples while there is inflow and outflow at each site. As a result, the proximity of the sites allows for a larger number of samples to be collected and thus a better understanding of the inflow and outflow loads at the detention basin

4.1.2 Wet Basins

For wet basin systems, settling, detention, decreased rates of discharge, in addition to trapping and filtration, comprise the processes by which water quality may be improved. Wet basins were ranked according to the permanent pool volume, drainage area, pond geometry, maintenance, and access to each site. Unfortunately, data on several of the design parameters that the JTF describes in their BMP design criteria such as permanent pool surface area, hydraulic residence time, and sediment forebay design were not available for many of the basins. The scoring system followed the structure of that for the detention basins. The categories that were used to rank the sites include: ratio of water quality detention volume to drainage area, the ratio of the length to the width of the basin, distance between the inlet and the outlet, the number of inlets and outlets, maintenance, access, and outlet design.

The identification of wet basins that meet the requirements of the sampling procedure and that meet the design requirements specified by the JTF was somewhat difficult. Several of the wet basins in Houston incorporate designs (i.e. the presence or absence of fountains and sediment forebays) and uses (i.e. drainage areas consisting of park, transportation, or industrial facility land uses) that may have strong effects upon the efficacy of these systems. Unfortunately, no studies were found that quantify the effects of these parameters.

4.1.3 Wetlands

The Harris County Flood Control District constructed the only artificial wetland systems in the Houston Metro Area. Two of these were planned for flood control and/or water quality uses while the primary function of the third was to serve as a wetland mitigation bank to replace wetlands destroyed by development activities. The only wetland system that was completed at the time of this report is located at the Greens Bayou Wetland Mitigation Bank. A second wetland area and wet basins are currently being designed and constructed at this location. The construction of two other wetland systems is near completion but the planting of wetland vegetation has not been completed. The vegetation is very important to the proper functionality of the system and even after planting activities are completed, the wetland likely will not function at peak effectiveness for several years while the vegetation stabilizes. One of these two artificial wetlands was constructed at Arthur Storey Park in southwest Houston. A wet basin is also located at this site. The second is a salt marsh located along the downstream portion of Brays Bayou. The salt marsh is intended to treat not only stormwater but also dry weather flows from Brays.

Wetlands are probably the most often studied types of BMP and although they are not currently a common method of storm water treatment in Houston, they have shown much promise to be used for the reduction of fecal pathogens during previous studies. At the time of this report, permission to access the right of way and to conduct sampling at wetland was not available.

4.1.4 Flood Control/Water Quality Basins

Flood control/water quality (FC/WQ) Basins are systems that are implemented as flood control structures but are enhanced to provide storm water quality improvements. The designs of these systems are similar to those of many wet basins, often with sediment forebays to provide initial sediment load reductions and permanent pool volumes that have detention areas designed to hold water between storm events. Design examples, maintenance suggestions, and other information on FC/WQ basins can be found in the Storm Water Quality Management Guidance Manual.

A FC/WQ basin was selected as a sample collection site for the project following the same ranking system used for the wet basins. No runoff event has yet been monitored at the site. FC/WQ 1 is a dual use (flood control/water quality) basin located at a residential subdivision in Harris County. The BMP was permitted by Harris County under the storm water quality permit number 8-0000055-7. The site is located near 29º 50’ 23” N and 95º 40’ 15” W. Samples will be collected from the inflow, the storage pool, and at the point of discharge.

4.1.5 Vegetative Filter Strips

Seven vegetative filter strips are currently permitted by the City of Houston and Harris County for stormwater quality management purposes. Because of the relatively low number of permits issued for this type of control and the variability in results, data collected over a small period of time for vegetative filter strips in the Houston metro area may not provide much information about these systems. In addition, of the vegetative filter strips permitted, only three were located in the watersheds of interest.

Permission to access one vegetative strip site for sample collection was requested at one of the three sites located within the watersheds of interest. This was the only site for which permit information was available. Reconnaissance was performed at the site to evaluate the status of this control including the stabilization, maintenance, and access to the required sample collection locations. This site was chosen because it meets the requirements of the permitting process and also because the control works in conjunction with other controls.

4.1.6 Grass Swales

Seventeen grass swales have been permitted in the Houston metro area; twelve by Harris County and five by the City of Houston. Permission to access a grass swale site located at the Westchase Park and Ride Facility in southwest Houston was requested. This site was chosen for several reasons. First, the site meets all of the requirements for the JTF permit. Second, the grass swale at this site works as a supplement to other controls. The results of studies performed on grass swales will continue to be collected and analyzed. The final decision on whether sample collection will be made after careful analysis of this data and taking into consideration all variables, including the frequency of grass swale permitting, the need for additional data on this type of control, and the potential for grass swales to improve the water quality of stormwater runoff for the Houston metro area.

CHAPTER 5

SAMPLE COLLECTION

Samples were collected at BMP sites during five runoff events from the two selected dry basins and the two selected wet basins.

5.1 DESCRIPTION OF FIELD ACTIVITIES

During runoff at four of the events, three to five samples were collected at both inflow and outflow to the basins. After the runoff events, additional samples were collected at the storage pools of the basins and from the outflow at a frequency of once every 24 hours. For the third event, sufficient runoff did not occur. As a result, sample collection activities were concluded after one round. Water samples were collected before any other work was done at a site unless holding time limits were compromised. Additional water samples were collected for TSS analysis and a YSI 6920 or 600XLM probe was used to measure the conductivity, dissolved oxygen, pH, salinity, temperature, and turbidity.

At times when discharge occurred into or out of the BMP, flow measurements were also collected. At dry basins, flow measurements were made using Manning's Equation, the Marsh McBirney Flo-Mate 2000 and flow area, the volume-based method, and/or the float-and-stopwatch method. At wet basins, flow measurements at the inflow were made using the Marsh

McBirney and flow area or using runoff/discharge calculations. At the outflow of the wet basins, flow was calculated from the depth at the weir (at WB1) or grate inlet (at WB2).

Field personnel chose the appropriate method(s) to use for all flow measurements collected at the BMP sites. When possible, more than one method was utilized to increase the opportunity to cross check flow calculation results. Because of the variability of the site designs and conditions, often the same methods could not be utilized at site locations throughout each sample collection event. The methods were chosen with consideration of the requirements of the site and access, safety concerns, and to try and ensure the greatest level of accuracy.

All water samples and flow measurements were collected using the methodology described in the "Urban Stormwater BMP Performance Monitoring" and/or the "Surface Water Monitoring Procedures" manuals (USEPA 2002; TCEQ 2003). The field standard operating procedures (SOP) document for this project is included in Appendix C.

5.2 DESCRIPTION OF SAMPLE COLLECTION/RUNOFF EVENTS

As discussed previously, several characteristics of the storm event have large effects upon the efficiency of the BMP. This section describes the runoff events and sample collection activities conducted for each event. For the first two runoff events, samples were collected at the detention basins DB1 (COH Permit Number 2002-0062) and DB2 (COH Permit Number 2004-0027). Samples were collected at both detention basins during the same event to test comparable runoff events at both sites. The Harris County Office of Emergency Management (HCOEM) monitors several rain gages in the areas nearby DB1 and DB2. Figure 2 shows the locations of the rain gages and the sample collection locations. The closest rain gage to each site was identified using the Thiessen polygon method. The majority of storms that occurred during the

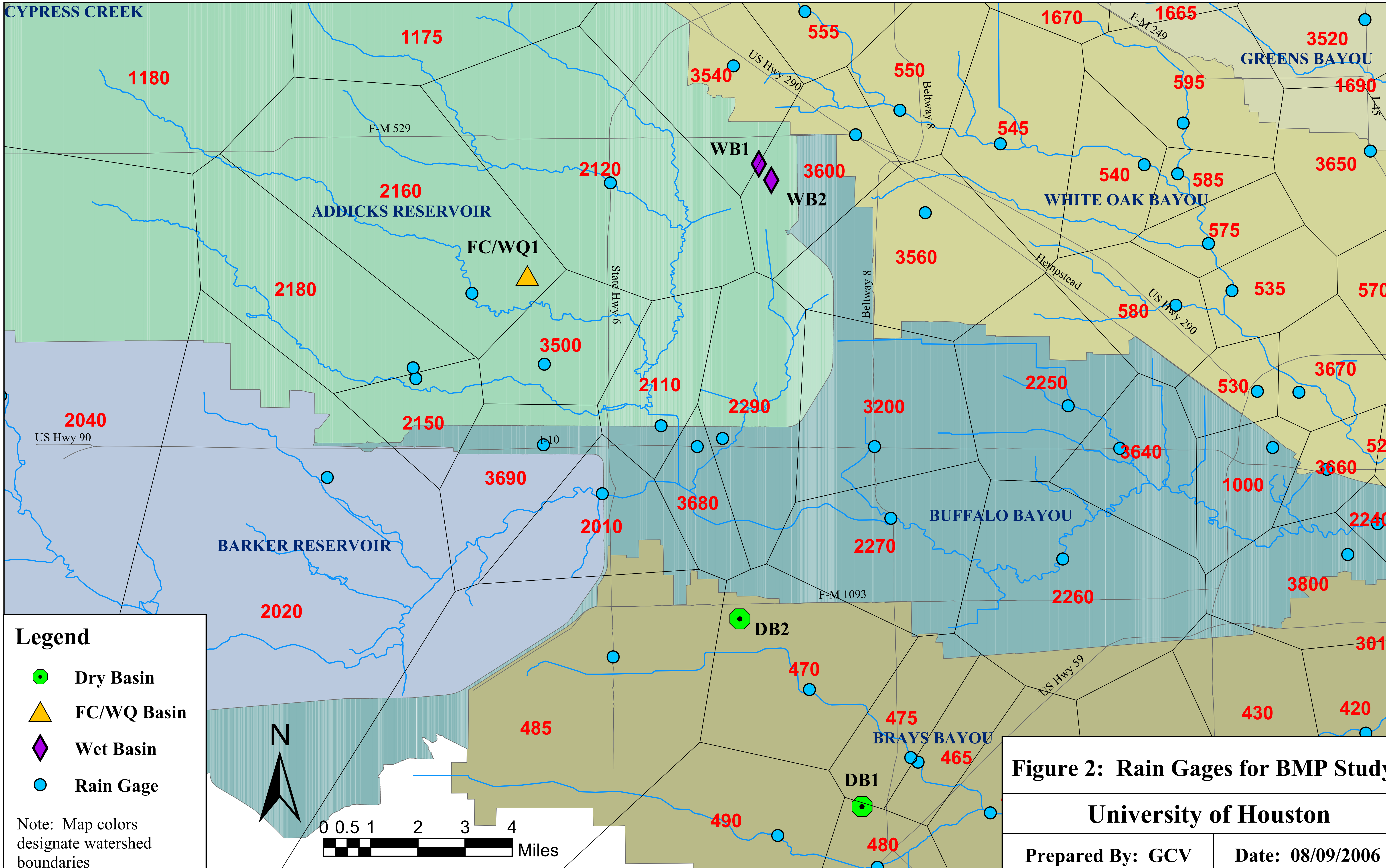


Figure 2: Rain Gages for BMP Study

University of Houston

Prepared By: GCV | **Date: 08/09/2006**

sample collection period were isolated and relatively small. As a result, rain gages that are located close to each other often show different rainfall amounts often making it difficult to obtain precise measurements for rainfall at the sample collection locations.

5.2.1 Event 1

The first sample collection event for this study was initiated on May 29, 2006. Rainfall accumulations measured by the gages and the total volumes of rain received for the drainage area are shown in Table 7. The rainfall lasted over a period of several days at each of the sites

Table 7: Daily Rainfall Accumulation and Volumes at DB1

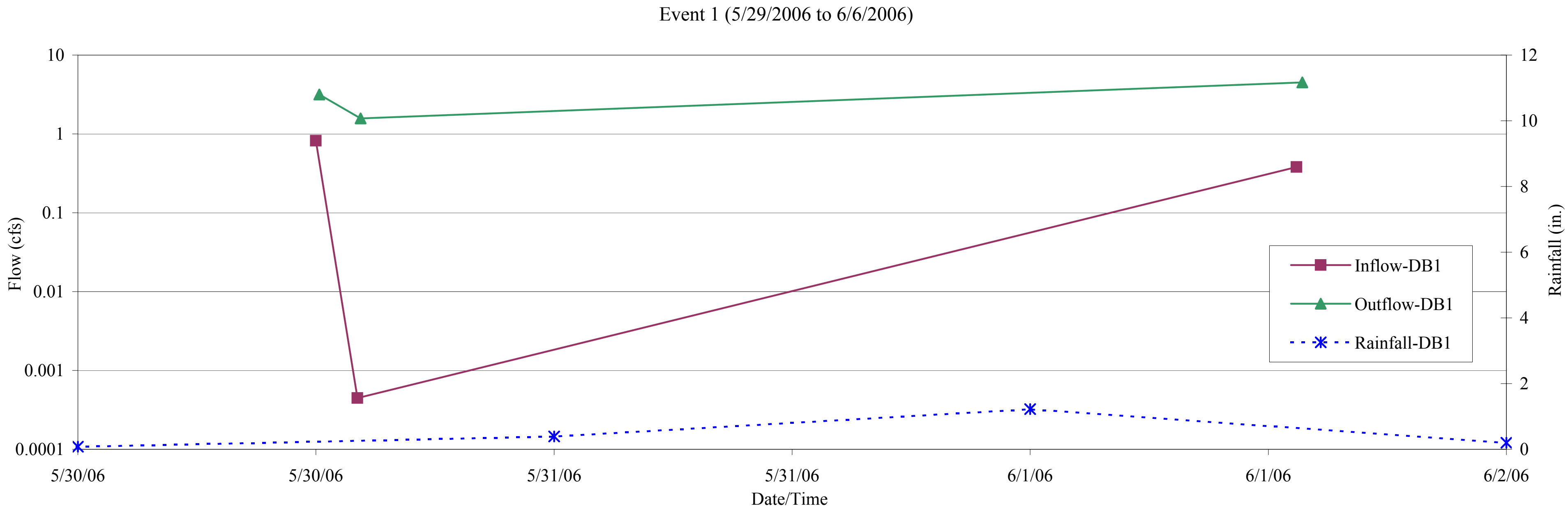
Day	Event	Day Number	Rainfall (in)	Volume (acre-ft)
5/29/2006	1	1	0.06	0.12
5/30/2006	1	2	0.26	0.51
5/31/2006	1	3	0.79	1.56
6/1/2006	1	4	0.85	1.68
6/2/2006	1	5	0.10	0.19
6/3/2006	1	6	0.00	0.00
6/4/2006	1	7	0.00	0.00
6/5/2006	1	8	0.00	0.00
6/6/2006	1	9	0.00	0.00
SUM	1	-	2.05	4.05
6/17/2006	2	1	0.65	1.29
6/18/2006	2	2	0.73	1.44
6/19/2006	2	3	0.28	0.55
6/20/2006	2	4	0.69	1.36
6/21/2006	2	5	0.51	1.01
6/22/2006	2	6	0.00	0.00
6/23/2006	2	7	0.33	0.66
6/24/2006	2	8	0.30	0.58
6/25/2006	2	9	0.00	0.00
SUM	2	-	3.48	6.90

(through the fifth day of sample collection at DB1 and the fourth day at DB2). The heaviest rainfall was not observed until the fourth day at DB1 and the second day of the event at DB2.

A graph of the rainfall and resulting inflow and outflow rates at DB1 is shown in Figure 3. Inflow into DB1 was observed for the first time on May 30 during a heavy, consistent rain. Most of the storm water discharged into the basin flowed within the boundaries of the concrete pilot channel of the basin and directly to the outflow pipe and no significant pool of water developed at the site. Prior to the storm, a large amount of sediment was observed deposited along the concrete pilot channel and this may have caused increased TSS and fecal pathogen concentrations at the outflow pipe. Unfortunately, the inflow and outflow ceased before a third sample could be collected on that day. The additional rains between day 2 and day 3 (Wednesday, May 31) and throughout day 3 did not cause inflow, outflow, or pooled water to be observed at DB1. On June 1, the estimated 0.85 inches of rain that fell in the area led to the accumulation of a storage pool (depth of 0.4 to 0.5 feet) near the outflow pipe for the first time during the first rain event. Samples of water were collected at the inflow, from the detention pool, and from the outflow.

The inflow and outflow at DB2 and the rainfall recorded at a nearby rain gage are shown in Figure 4. The drainage area served by DB2 first received a significant volume of rainfall on Monday, May 29, 2006. Scattered rainfall lasted over approximately a six hour period and ranged from very low to medium intensity. Four rounds of samples were collected at the inflow and at the outflow at DB2. Inflow was observed at site DB2 throughout the afternoon of day 2 and a pool of stormwater accumulated in the basin. Three rounds of water samples were collected at the inflow, the detention pool, and at the outflow of the basin. DB2 received more inflow and a slight increase of 0.3 inch in the temporary pool depth was observed. Samples were collected at the inflow, the detention pool, and at the outflow of DB2 on May 31.

Figure 3: Inflow and Outflow at Detention Basin One During Events 1 and 2



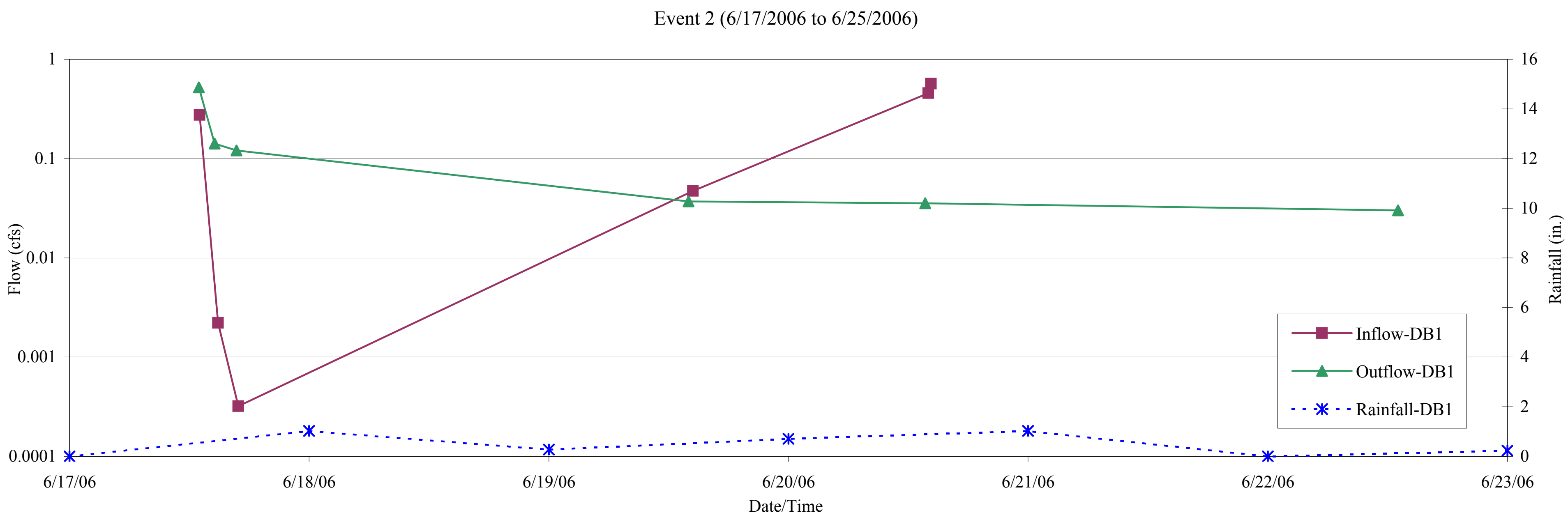
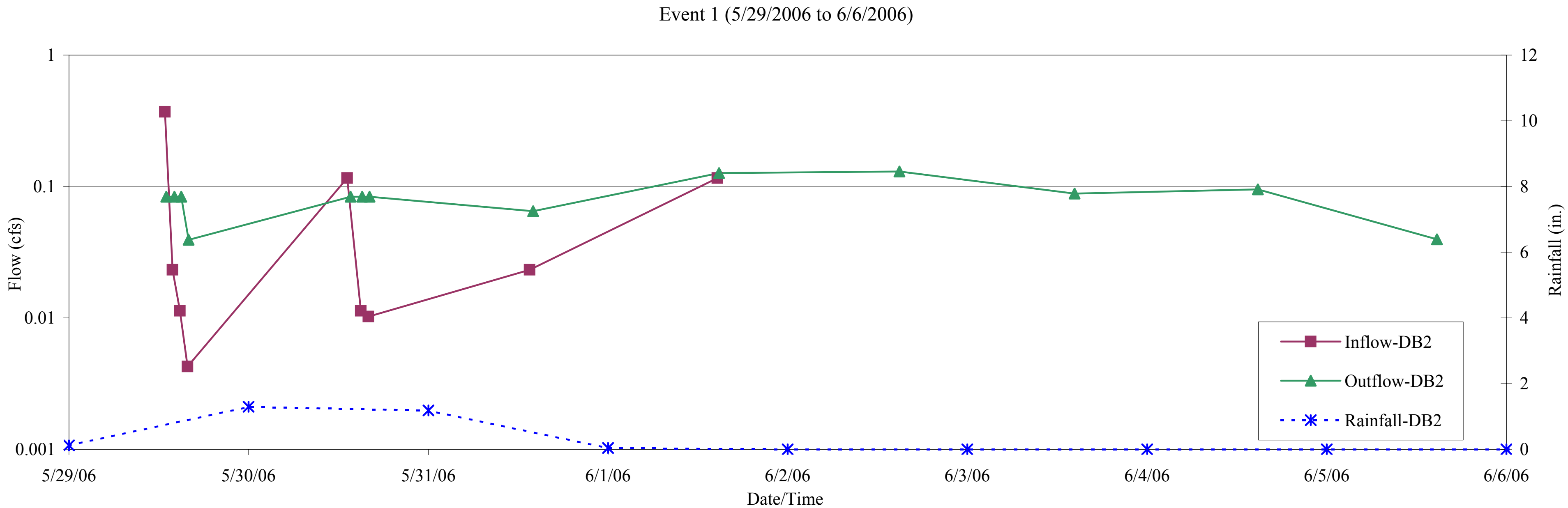
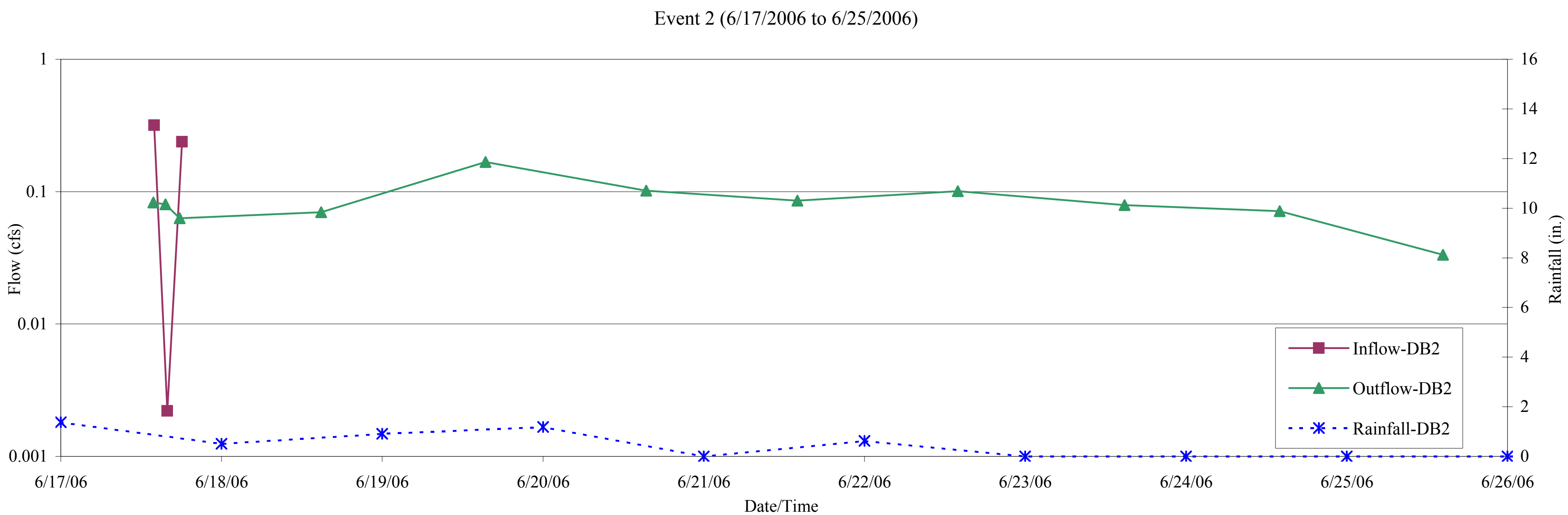


Figure 4: Inflow and Outflow at Detention Basin Two During Events 1 and 2





No additional rainfall was observed or reported by HCOEM after June 1 through the termination of sampling activities for runoff event 1 on June 5. Neither inflow nor outflow at DB1 was observed subsequent to June 1; however, the detained water from the runoff event was detained through June 4. Samples of water were collected at the temporary pool at DB1 daily while water remained pooled. At DB2, samples were collected from both the detained pool of stormwater and from the outflow throughout June 5. Subsequent to this date, no further discharge from the basin was observed.

5.2.2 Event 2

The second runoff event began on June 17, 2006 and, similar to the first runoff event, rain lasted for several days. The total rainfall accumulation per day and total rainfall volumes are shown in Table 8 and in Figures 3 and 4. DB1 received rain through June 24 and DB2 received rain through June 22. Sample collection lasted for 9 days at both sites. DB1 did not have discharge past June 21 but samples were collected from the temporary pool to test the changes within the pool concentration throughout sample collection at DB2 where discharge lasted through the 9^{th} day. The accumulation during this second event was much higher than that during the first event. In total, almost 3.5 inches of rain fell at DB1 and 4.6 inches at DB2.

Inflow was observed at DB1 but only a relatively small volume of water was stored. The storage pool at DB2 for this event was much larger than during the first event. There was a small amount of discharge observed at the overflow berm on June 20, the second heaviest day of rain. A sample was collected from the overflow berm on this day.

Table 8: Daily Rainfall Accumulation and Volumes at DB2

Day	Event	Day Number	Rainfall (in)	Volume (acre-ft)
5/29/2006	1	1	0.12	0.13
5/30/2006	1	2	1.30	1.47
5/31/2006	1	3	1.18	1.34
6/1/2006	1	4	0.04	0.04
6/2/2006	1	5	0.00	0.00
6/3/2006	1	6	0.00	0.00
6/4/2006	1	7	0.00	0.00
6/5/2006	1	8	0.00	0.00
6/6/2006	1	9	0.00	0.00
SUM	1	-	2.64	2.98
6/17/2006	2	1	1.38	1.56
6/18/2006	2	2	0.51	0.58
6/19/2006	2	3	0.91	1.02
6/20/2006	2	4	1.18	1.34
6/21/2006	2	5	0.00	0.00
6/22/2006	2	6	0.63	0.71
6/23/2006	2	7	0.00	0.00
6/24/2006	2	8	0.00	0.00
6/25/2006	2	9	0.00	0.00
SUM	2	-	4.61	5.21

Under typical runoff conditions, high concentrations of bacteria in storm water runoff are expected during the first flush. This is the runoff that occurs as a result of the first 0.5 inches of rainfall. After the first flush, the concentrations are expected to decrease. The first flush during this runoff event occurred throughout an extended period of time; this may have caused increased resuspension of sediments in the temporary pools and reduced the ability of contaminants to settle out. This could reduce the ability of the detention basins to function effectively.

To develop a better understanding of the effectiveness of the detention basins, a large number of samples was collected at each of the sampling locations. At DB1, samples were collected when possible yet the detention basin accumulated less of a storage volume than was expected for the volume of rain that occurred.

5.2.3 Event 3

The third runoff event occurred on July 18, 2006. At HCOEM rain gage number 3600, only 0.04 inches of rainfall were received. The accumulation shown at other nearby rain gages was less than 0.2 inches. The sample collection team arrived at WB2 before the rain started and the entire rainfall event was observed onsite. Unfortunately, a minimal amount of runoff was observed that did not last long enough to sustain more than one round of sample collection. One sample was collected at the inflow, the permanent pool, and the outflow. These samples show the effect that the basin has on the discharge created by a low-intensity, short duration storm. The inflow samples were collected from the drainage culverts along the streets. Samples at the outflow were collected adjacent to the basin outlet. No runoff was observed into WB1 during this storm and no samples were obtained there. Table 9 contains the rainfall amounts and total volumes for the discharge areas to WB1 and WB2 during events 3 and 4.

5.2.4 Event 4

The fourth runoff event began on July 22, 2006. The rainfall occurred over two days and the nearest rain gage (HCOEM gage # 3600) received 0.24 inches of rain. Most of the rain was recorded on July 23. The total rainfall for the event is just under half of the maximum water quality volume intended to be treated by the wet basins. Rainfall occurred on July 25; however, the discharge from the basins had decreased greatly over previous two days and this storm was considered to be a separate event. Table 10 contains the rainfall amounts and total volumes for the discharge areas to WB1 and WB2 during events 3 and 4.

Table 9: Rain Volumes and Accumulation at WB1 (Runoff Events 3, 4, and 5)

Day	Event	Day Number	Rainfall (in)	Volume (acre-ft)
7/18/2006	3	1	0.04	0.04
7/22/2006	4	1	0.04	0.04
7/23/2006	4	2	0.20	0.18
7/24/2006	4	3	0.00	0.00
Total	**4**	**-**	**0.24**	**0.22**
8/10/2006	5	1	0.12	0.11

Table 10: Rain Volumes and Accumulation at WB2 (Runoff Events 3, 4, and 5)

Day	Event	Day Number	Rainfall (in)	Volume (acre-ft)
7/18/2006	3	1	0.04	0.07
7/22/2006	4	1	0.04	0.07
7/23/2006	4	2	0.20	0.33
7/24/2006	4	3	0.00	0.00
Total	**4**	**-**	**0.24**	**0.39**
8/10/2006	5	1	0.12	0.20

5.2.5 Event 5

The fifth runoff event began on August 10, 2006. A total of 0.12 inches of rainfall was received at the sites, as shown in Tables 9 and 10. Rainfall occurred on only the first day of the event. Runoff was observed from the street into the basins at both sites and three rounds of samples were collected during this first day. Discharge was observed over three days and outfall samples were collected at each of the two sites over this period. In addition, samples were collected each day from the permanent pool.

5.3 LABORATORY METHODOLOGY

All of the water samples were transported to the University of Houston laboratory for analysis of the *E. coli* concentrations. Laboratory analyses for *E. coli* were completed within 8 hours of sample collection. To ensure accuracy, the methodology discussed in the "Surface Water Quality Monitoring Procedures" manual was followed during all sampling and analysis procedures (TCEQ 2003).

The IDEXX© procedure was followed for the quantification of all *E. coli* samples. All samples were analyzed in duplicate at three dilutions: 1:1, 1:10, and 1:100. The reading of all sample results and determination of *E. coli* concentrations was conducted following the IDEXX© reporting guidelines (TCEQ 2003). Samples were incubated at 35 +/- 0.5 degrees Celsius. The results for dilutions/replicates that had positive cell counts within the 30 and 80 range were used to make all analyses. If more than one tray produced a positive cell count within this range, the average of these trays was calculated. If all dilutions were below the acceptable range for positive results, the results from the lowest dilution (usually 1:1) were used. If all dilutions were above the acceptable range for positive result counts, the results from the highest dilution (usually 1:100) were used. The samples were read after 24 to 28 hours of incubation. The laboratory standard operating procedure (SOP) has been included in Appendix C.

5.4 EFFICIENCIES OF DRY BASINS

5.4.1 Dry Basin 1

Table 11 shows the *Escherichia coli* concentrations at the inlets, outlets, and the storage pools of DB1, as well as, the flow weighted removal efficiencies obtained for runoff events one and two. The geomean values were calculated as the flow weighted geomean concentrations for each location. As can be seen from the table, there is a large difference between the efficiencies calculated for these two events. There was a percent increase of 1858% for runoff event 1 and a percent increase of 33.5% during runoff event two. The differences between the events highlight the importance of the variability of the storm, the natural environment, and the maintenance of detention basins to achieve fecal pathogen reductions.

Graphs of the *E. coli* concentration at the inflow, outflow, and within the storage pool during events one and two are shown in Figure 5. During both events, the storage pools were not significant and the period of discharge lasted only the first few days. Samples from the pools were obtained through the eighth day during event one and through the ninth day during event two to measure the changes in the fecal pathogen concentrations over time.

The graph for event one shows that the outflow concentrations were much higher than those of the inflow throughout the event. As mentioned previously, sediment accumulation along the concrete pilot channel of DB1 was observed before both runoff events. Pictures of the sediment that had accumulated along the channel and water flowing through the channel are shown in Figure 6. The inflow likely caused resuspension of the fecal pathogen indicators and sediment as it traveled along the channel. This may have increased the concentrations that were

Table 11: E. coli Concentrations at DB1 (Runoff Events 1 and 2)

	Date	**Round**	**Inlet Concentration (MPN/100ml)**	**Pool Concentration (MPN/100ml)**	**Outlet Concentration (MPN/100ml)**	**Reductions Through Time***
Event 1	5/30/06	1	41	-	796	-198%
	5/30/06	2	50	-	2517	-842%
	6/1/06	1	2016	5380	11895	-4352%
	6/2/06	1	-	296	-	-
	6/3/06	1	-	804	-	-
	6/4/06	1	-	1904	-	-
	GEOMEAN		2.67E+02	1.25E+03	5.23E+03	-
	% REDUCTION		-1858%			
Event 2	6/17/06	1	32	-	136	85%
	6/17/06	2	7	-	780	16%
	6/17/06	3	12	-	626	32%
	6/18/06	1	12	366	626	32%
	6/19/06	1	1725	1287	2706	-193%
	6/20/06	1	1349	1548	3003	-225%
	6/20/06	1	2044	-	-	-
	6/21/06	1	-	57	-	-
	6/22/06	1	-	61	82	91%
	6/23/06	1	-	19	-	-
	6/23/06	1	-	245	-	-
	6/23/06	2	-	6535	-	-
	6/24/06	1	-	287	-	-
	6/25/06	1	-	9	-	-
	GEOMEAN		9.23E+02	2.13E+02	1.23E+03	-
	% REDUCTION		-33.5%			

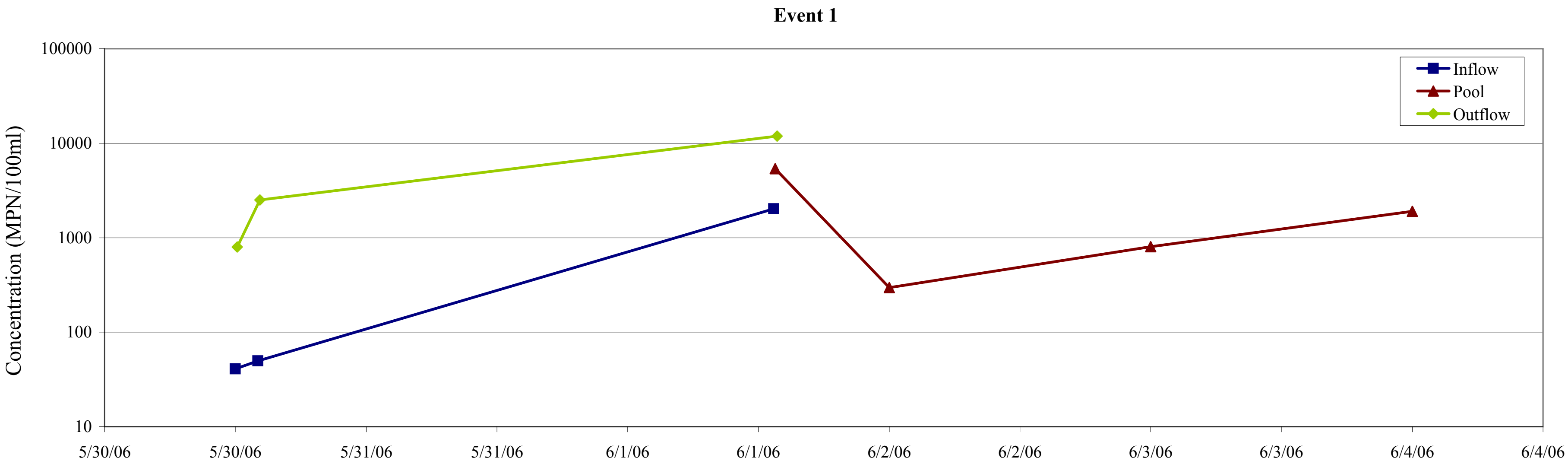
In the case of duplicates, values are calculated as the average of the two samples
Negative percent reductions represent increases in bacteria loads
* Reductions through time are calculated as: $RED = (INF_{GM} - OUT)/INF_{GM}$

where: RED is the percent reduction through time (%)

INF_{GM} is the geometric mean of the inflow

OUT is the outlet concentration for each date and round

Figure 5: Graph of E. coli Concentrations at DB1 (Runoff Events 1 and 2)



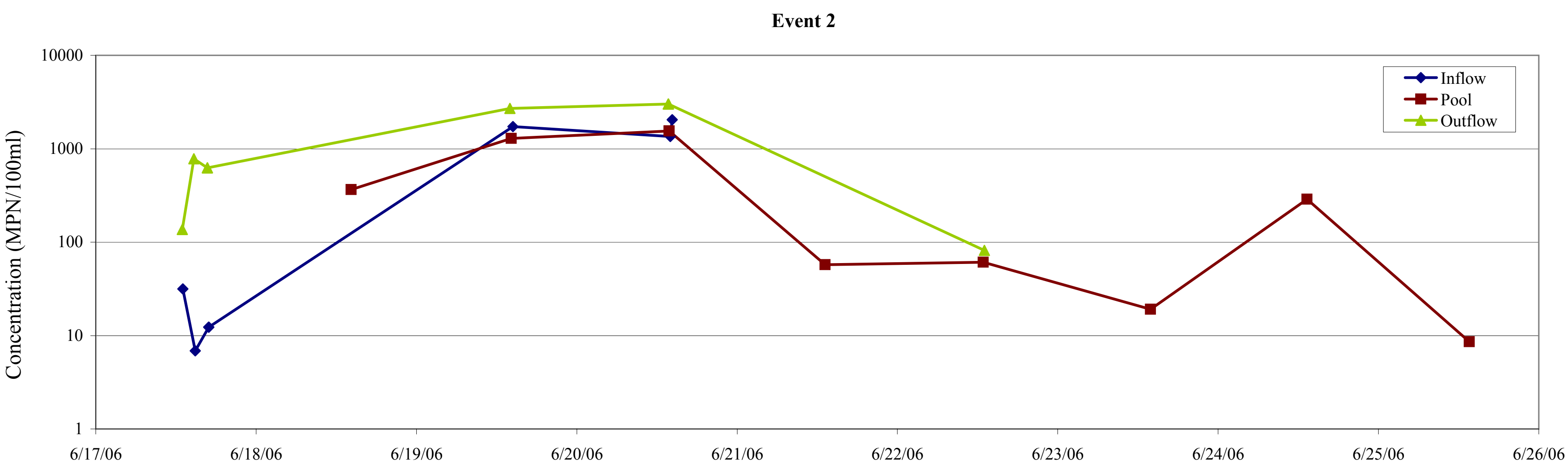


Figure 6: Sediment Accumulation along the Concrete Channel at DB1

Sediment accumulation during dry weather conditions on 5/28/2006

Runoff flowing through concrete channel on 5/31/2006 discharged from the basin. In addition, the long duration of the rainfall event may have led to continual resuspension, compounding the problem. Studies have shown high concentrations and low death rates for fecal pathogens including *E. coli* in sediment (Stenstrom and Carlander 2001). Two sediment samples were collected at DB1 to help analyze the effect that resuspension may have played. Table 12 shows the sediment concentrations. The sediment sample collected along the edge of the pool surface had 716 MPN/100g. The sample collected from the sediment that had accumulated in the concrete channel showed 25,800 MPN/100g. This suggests that the sediment that had accumulated in the concrete channel contributed to the increased concentrations of the outflow and the pool.

Table 12: *E. coli* Concentrations from Sediment Collected at Dry Basins

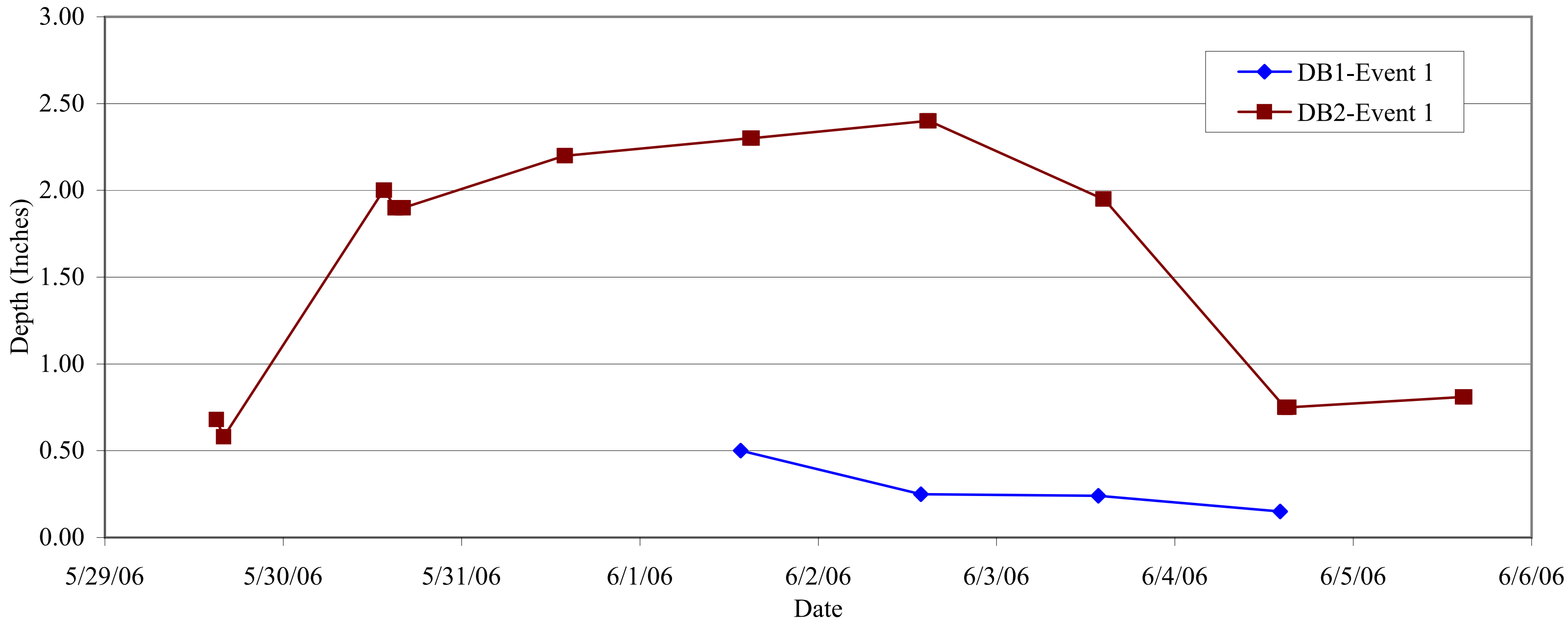
Date	BMP	MPN/100g Sediment	Location
6/23/06	DB1	1.02E+03	Sediment Along Edge of Pool Water Surface
6/23/06	DB1	2.58E+04	Sediment Accumulated in Channel
6/24/06	DB2	2.27E+02	Sediment Along Edge of Pool Water Surface

MPN – Most Probable Number, g - grams

DB1 is a conventional detention basin. The outflow device does not restrict the flow as much as that of an extended detention basin. As a result, the storage pool does not store much water except for very large storms when flooding is more likely. The concentrations at the pool and from the outflow measured June 1 were very similar. Fecal pathogen indicator concentrations at the small pool that did develop showed a decrease after runoff had stopped, then a somewhat constant increase in concentration. This may be a result of initial sedimentation rates that decreased the bacteria concentrations adsorbed to the larger easily settleable concentrations. The increase after the initial decrease is difficult to explain. After the point at which the pool had its lowest concentration, the pool depth had reached a very low point. It is possible that minor disturbances at this depth could lead to resuspension of sediments and fecal pathogen indicators. Unfortunately, by the time that a substantial detention volume had accumulated, no additional outflow from the system was observed. Therefore, there is no outflow data available to show how the pool concentrations would have affected discharge concentrations. A strong correlation, however, has been shown between the outflow concentrations and the pool concentrations in both of the dry basins. In the case of smaller treatment pools, net sedimentation occurs at a much slower rate due to the large effect of minor disturbances such as wind and animals to resuspend sediments. Sedimentation is very important to the efficiency of detention basins, so that the lack of definite pool formation could greatly reduce the ability of DB1 to function properly. Since birds were observed at the site, these could have provided an additional source of fecal pathogens. Due to the small pool size, deposition of feces could have a significant effect upon the concentrations in the water as compared to that upon smaller pools over which the feces would be much more diluted. The depth of the pools at DB1 and DB2 through sample collection can be seen in Figure 7. These graphs clearly show an important difference between the formation and discharge from the storage volume at the two dry basins. There are clear net accumulation and discharge phases shown for DB2 whereas for DB1 there is a slight accumulation and discharge initially and no additional discharge was observed after the initial period.

Figure 8 shows the values of several of the other parameters that were tested at DB1 during events one and two. The graphs for turbidity and total suspended solids (TSS) concentrations show strong similarities to the trends of *E. coli*. Statistically significant correlations were not observed between TSS and the *E. coli* concentrations. A correlation was,

Figure 7: Storage Pool Depths for Dry Basins During Events 1 and 2



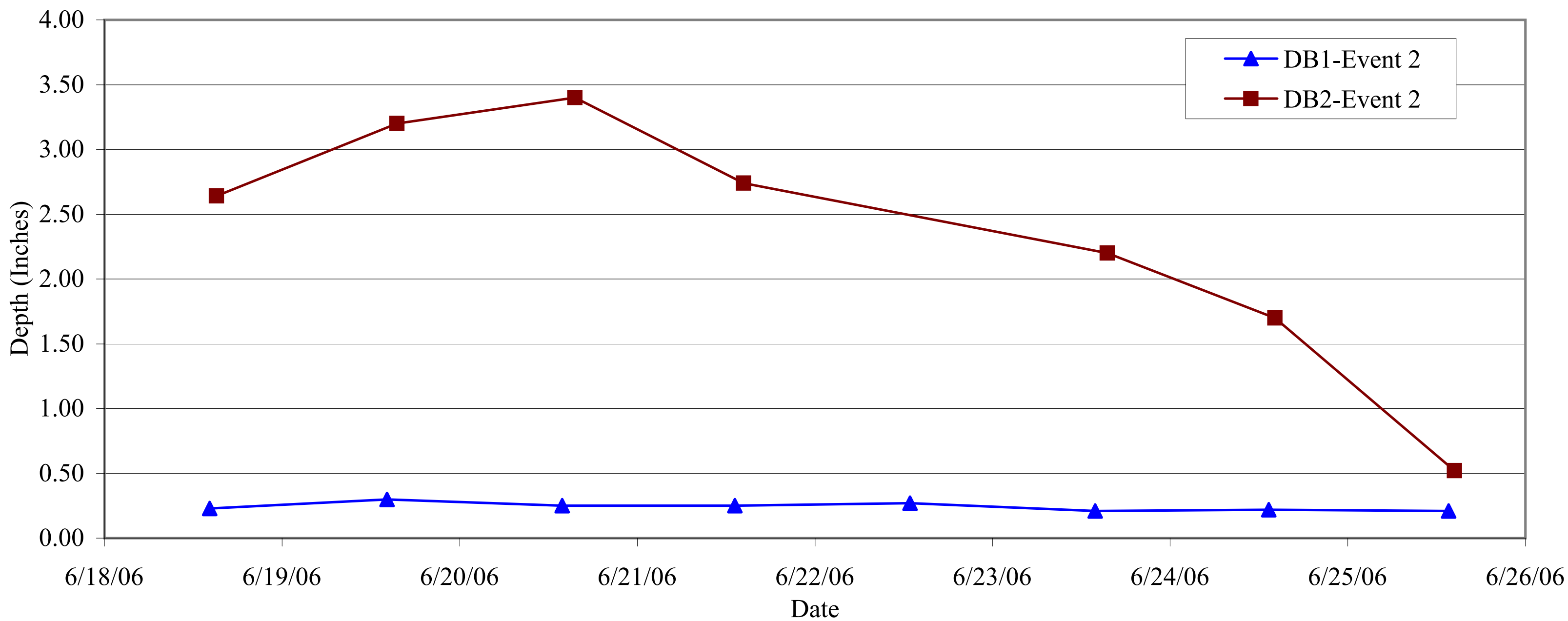


Figure 8: Additional Parameter Values Tested at Dry Basin 1 (Event 1)

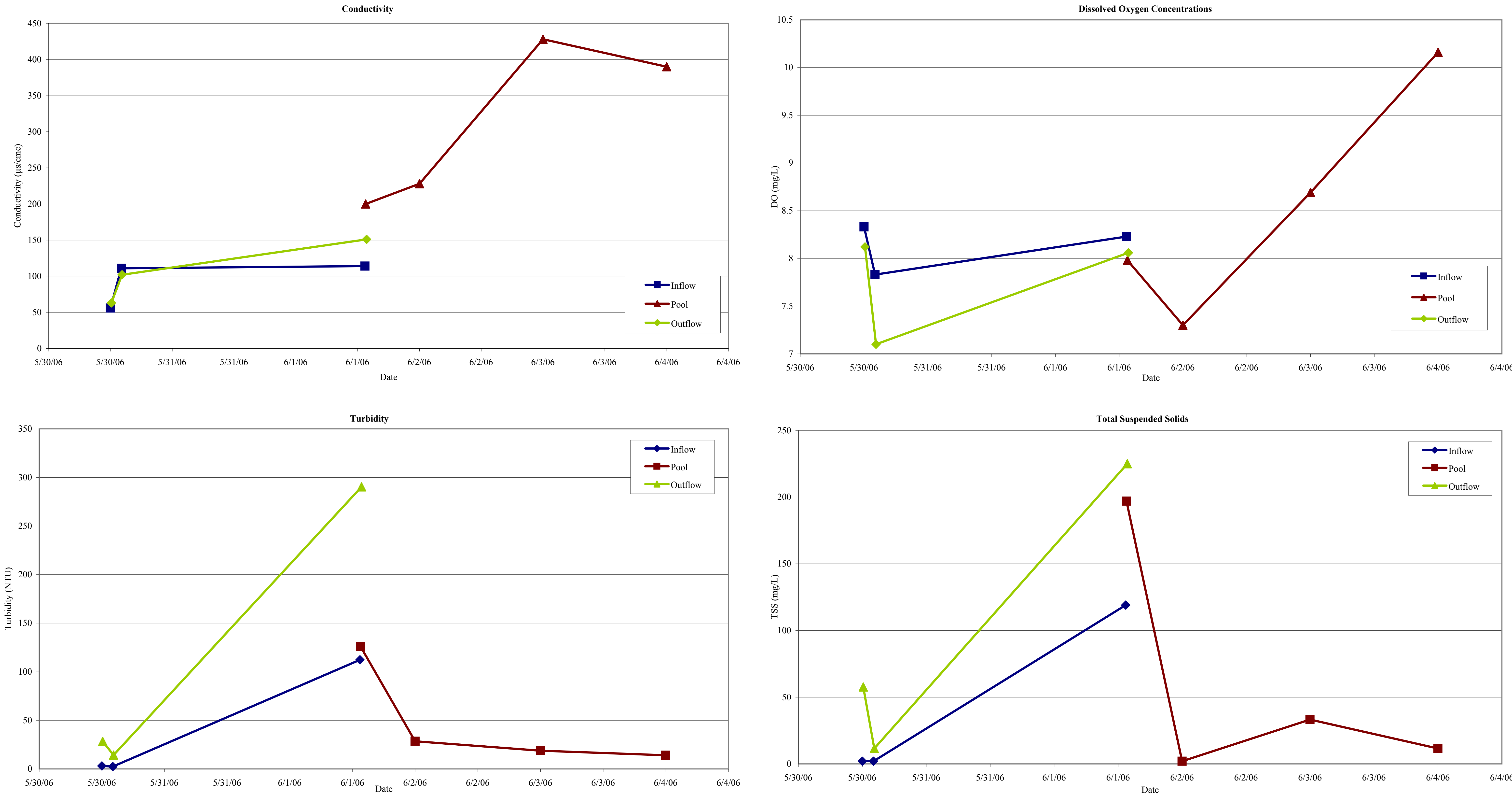
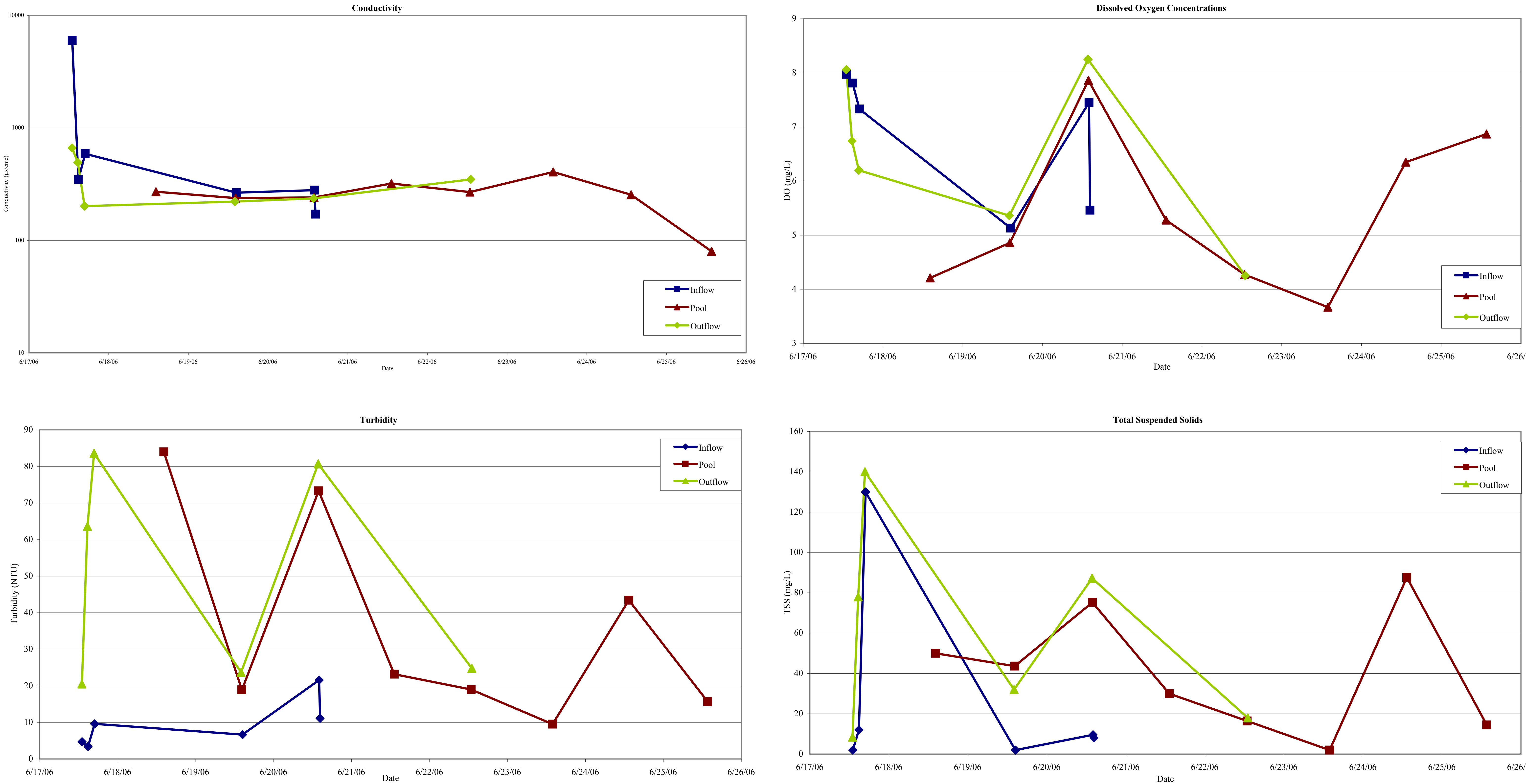


Figure 8: Additional Parameter Values Tested at Dry Basin 1 (Event 2)



however, found between turbidity and *E. coli* (R^2 values ranged from 0.31 to 0.78 although there were few data points to add definite statistical significance). The turbidity and TSS concentrations at the outflow were also much higher than at the inflow. This adds support to the hypothesis that the sediment in the concrete channel played a role in increasing the indicator concentrations at the outflow. The increases in the dissolved oxygen concentration of the pool that occurred from June 2 to June 4 also give credence to the theory that there were disturbances to the pool during this period of time since turbulence would have caused both mixing with air and resuspension of microorganisms that had settled out.

5.4.2 Dry Basin 2

Table 13 presents the concentrations at the inflow, pool, and outflow of DB2 during events one and two. The flow-weighted percent removal efficiencies for the detention basin are also shown. During event one, approximately 67% of the fecal pathogen indicator concentration was removed and for event two, the basin had a removal efficiency of 70%. The difference between the two efficiencies is minimal considering, as shown in Table 8, DB2 received almost 2 inches more rainfall during event two than during event one. This difference is almost twice as much as the total rainfall received during event one (2.64 inches).

Figure 9 illustrates the changes in the *E. coli* concentrations over time. Striking differences are visible between the concentrations and trends at DB1 and DB2. One of the most important operational differences between these two dry basins is the extent of formation of the storage pool and the period of detention (DB2 is an extended detention basin). As can be seen in Figure 7, the basin discharged over about 7 days during both events and held a much deeper pool

Table 13: *E. coli* Concentrations at DB2 (Runoff Events 1 and 2)

	Date	Round	Inlet Concentration (MPN/100ml)	Pool Concentration (MPN/100ml)	Outlet Concentration (MPN/100ml)	Reductions Through Time*
Event 1	5/29/06	1	424	-	1683	-24%
	5/29/06	2	761	-	3365	-148%
	5/29/06	3	435	-	-	-
	5/29/06	4	552	-	8810	-548%
	5/30/06	1	345	3179	4070	-199%
	5/30/06	2	511	2519	2783	-105%
	5/30/06	3	587	2861	2708	-99%
	5/31/06	1	2442	1408	2274	-67%
	6/1/06	1	6255	147	192	86%
	6/2/06	1	-	86	351	74%
	6/3/06	1	-	70	58	96%
	6/4/06	1	-	27	142	90%
	6/4/06	2	-	1	-	-
	6/5/06	1	-	1638	2034	-50%
	GEOMEAN		1.36E+03	2.57E+02	4.46E+02	-
	% REDUCTION		67.2%			
Event 2	6/17/06	1	567	-	4923	-227%
	6/17/06	2	1520	-	984	35%
	6/17/06	3	6210	382	813	46%
	6/18/06	1	-	294	2649	-76%
	6/19/06	1	-	2269	2187	-45%
	6/20/06	1	-	1567	3432	-128%
	6/21/06	1	-	43	25	98%
	6/22/06	1	-	46	59	96%
	6/23/06	1	-	9	44	97%
	6/24/06	1	-	40	161	89%
	6/25/06	1	-	838	1587	-5%
	GEOMEAN		1.51E+03	1.69E+02	4.15E+02	-
	% REDUCTION		72.4%			

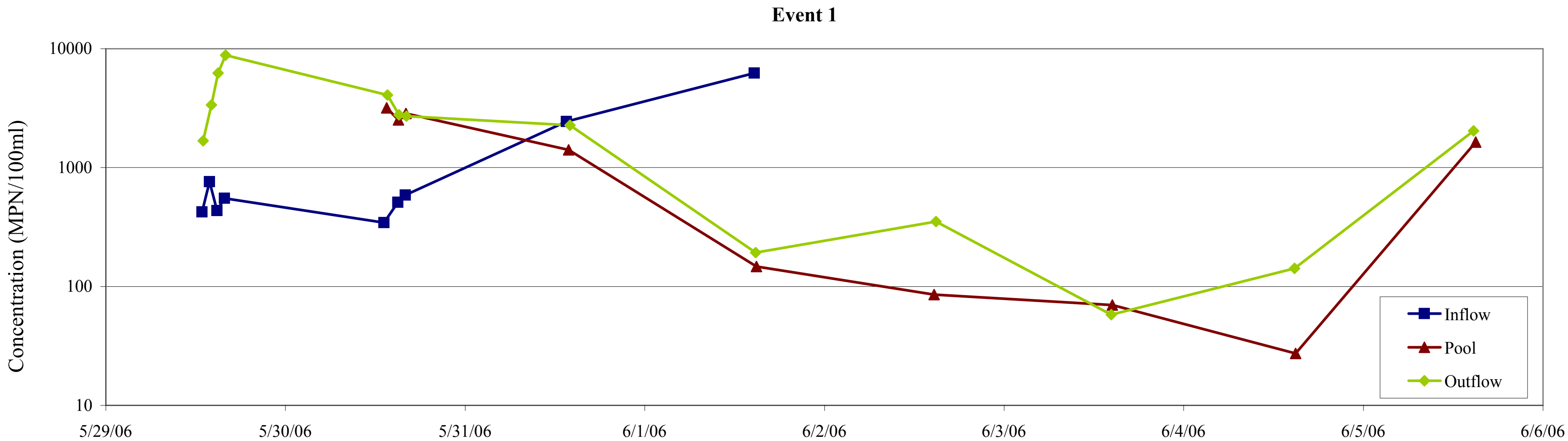
In the case of duplicates, values are calculated as the average of the two samples
Negative percent reductions represent increases in bacteria loads
* Reductions through time are calculated as: $RED = (INF_{GM} - OUT)/INF_{GM}$
where: RED is the percent reduction through time (%)
INF_{GM} is the geometric mean of the inflow
OUT is the outlet concentration for each date and round

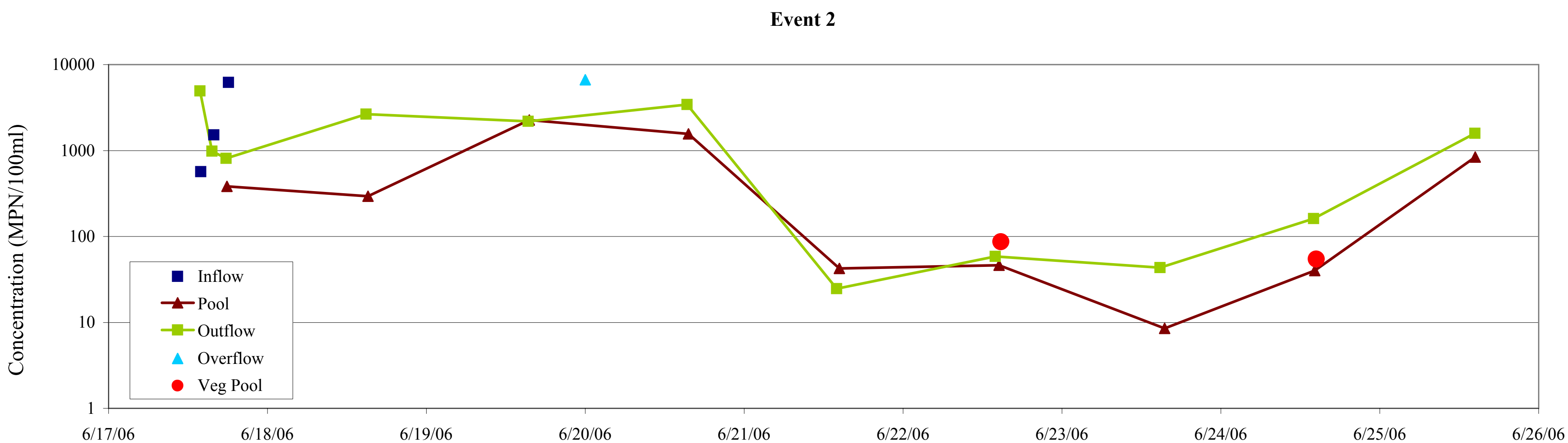
than DB1. Since sedimentation is one of, if not the dominant process by which fecal pathogen concentrations are decreased, the difference between these two basins is very important.

The *E. coli* concentrations at the inflow of DB2 showed a strong upward trend over time during both events. For event one, this trend is in contrast to the expected first flush affect. The first flush should result in fecal pathogen concentration peaks at the inflow during the first 0.5 inches of runoff that would tail off over time. By considering the amount of rainfall received over the first two days (as shown in Table 10), the first flush should have occurred on May 30. The drainage area to the basin received about 1.3 inches (as reported by HCOEM) and the concentrations after this day would be expected to decrease over time. Because of the extended duration of the rainfall event, the steady runoff volume over time could be less likely to cause a strong flush of the contaminants that had accumulated over time. The concentration of inflow during the second runoff event also showed a strong increase over the first day. Additional runoff was not observed at the site on subsequent sample collection days.

During the first runoff event, the pool and the outflow exhibited high initial concentrations that decreased steadily over the next six days. During the second event, the concentrations at both locations remained high over the first three days and then a steady die off occurred over the subsequent 5 to 6 days. As in DB1, the high concentrations initially could be the result of the resuspension of accumulated sediments; DB2 had a much smaller volume of accumulated sediments along the concrete pilot channel than DB1, however. The die-off of concentrations over the subsequent 5 to 6 days can be explained by the processes occurring within the detained volumes of stormwater runoff. Sedimentation, exposure to solar radiation, and other conditions that increase bacteria death rates such as competition/predation are expected to have reduced the

Figure 9: Graph of *E. coli* Concentrations at DB2 (Runoff Events 1 and 2)





concentrations within the pool and thus of the discharge. The pool and outflow concentrations also showed very consistent trends throughout this period. The *E. coli* concentrations increased over the last 1 to 2 days during which samples were collected. At this point a very large concentration of tadpoles where observed. In addition, birds were seen at the site throughout the event. With the combination of a very shallow depth at this time, small fluctuations caused by the animals or wind could have caused high amounts of resuspension of both sediments and fecal contaminants. Direct deposition by the birds into the smaller volume of water could have also increased fecal bacteria concentrations. The fluctuations in turbidity, conductivity, and total suspended solids support this hypothesis. As shown in Figure 10, the turbidity in both the pool and the outflow increased over the last two days during which the *E. coli* concentrations also increased.

Table 14 shows the concentrations for some samples collected during event two at three additional locations. On June 20, a slight overflow was observed at the berm that controls and releases volumes that exceed the designed maximum. A sample of water was collected from the overflow and tested to see what the contribution could be from this. The water had a concentration of 6,677 MPN/100ml. This is much higher than the concentrations that were observed at both the pool and the outflow. The second and third locations were collected at shallow portions of the pool. Water in the heavily vegetated and shallower regions of the pool appeared much less turbid than the main pool volume. These samples were collected from these areas to see if these factors would increase or reduce bacteria removal rates. The lower turbidities may have been the result of the restriction of wind disturbance on the water or the trapping of particulates by plants. Both samples of water collected from these regions had slightly higher concentrations of *E. coli* than did the normal pool collection location and the outflow on June 22.

Figure 10: Additional Parameter Values Tested at Dry Basin 2 (Event 1)

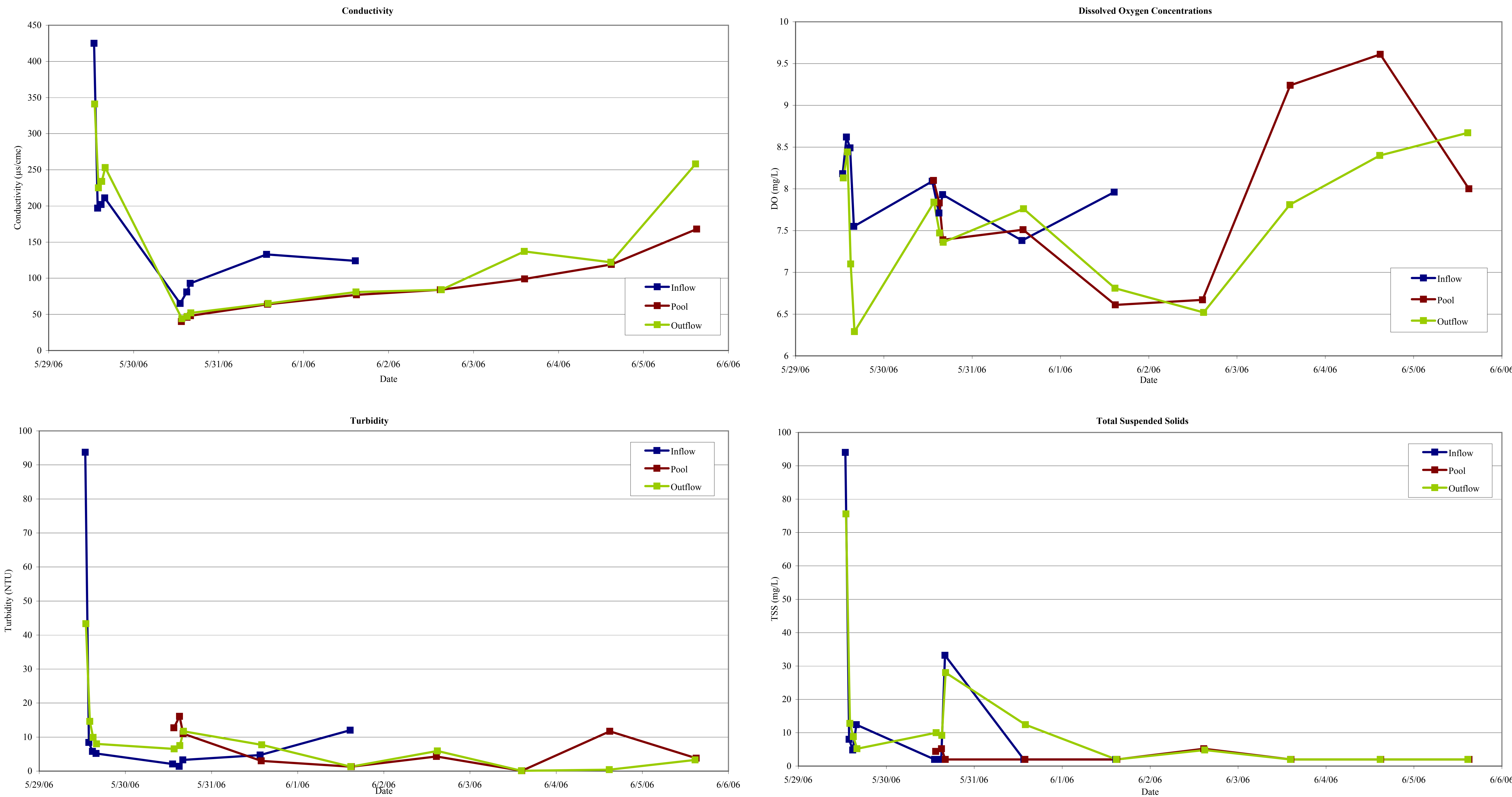
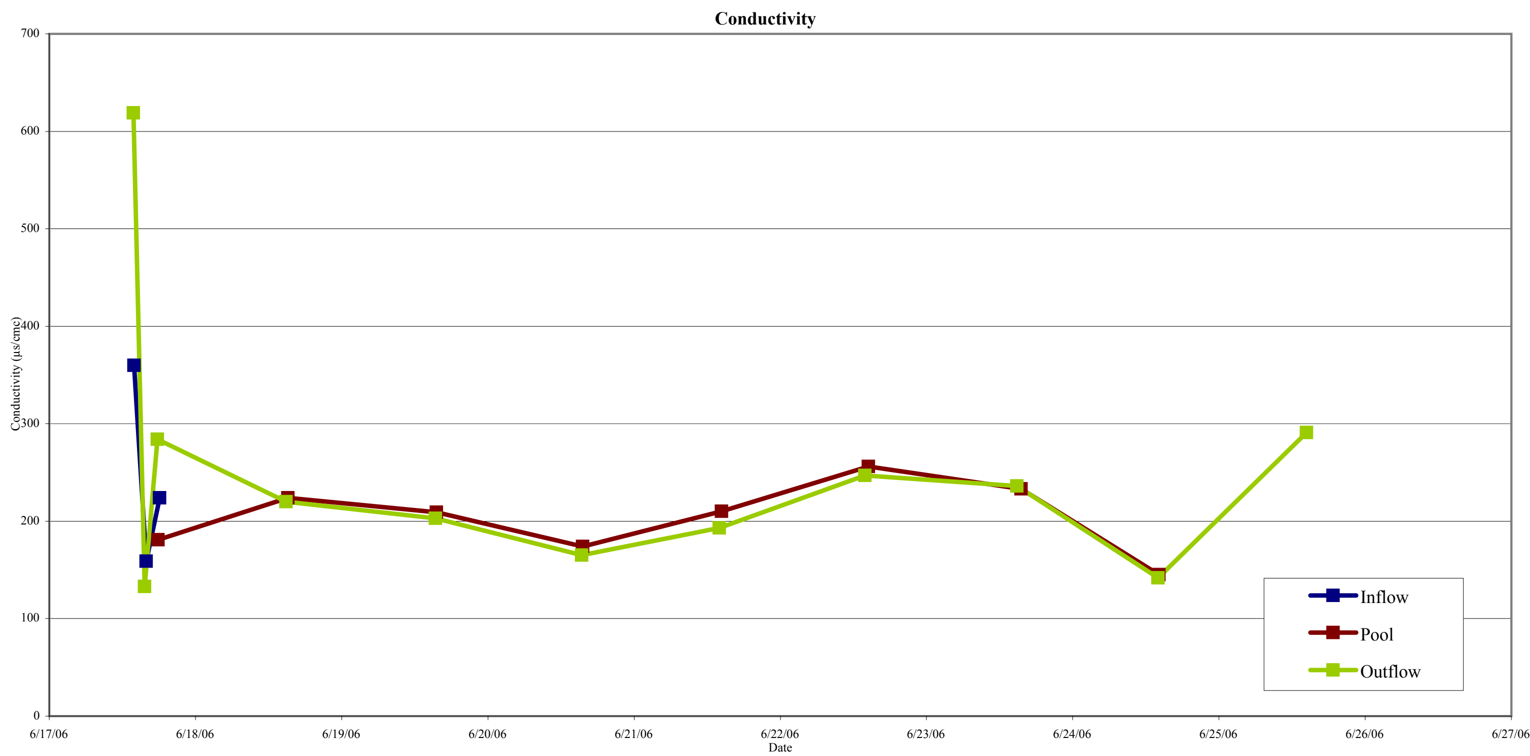
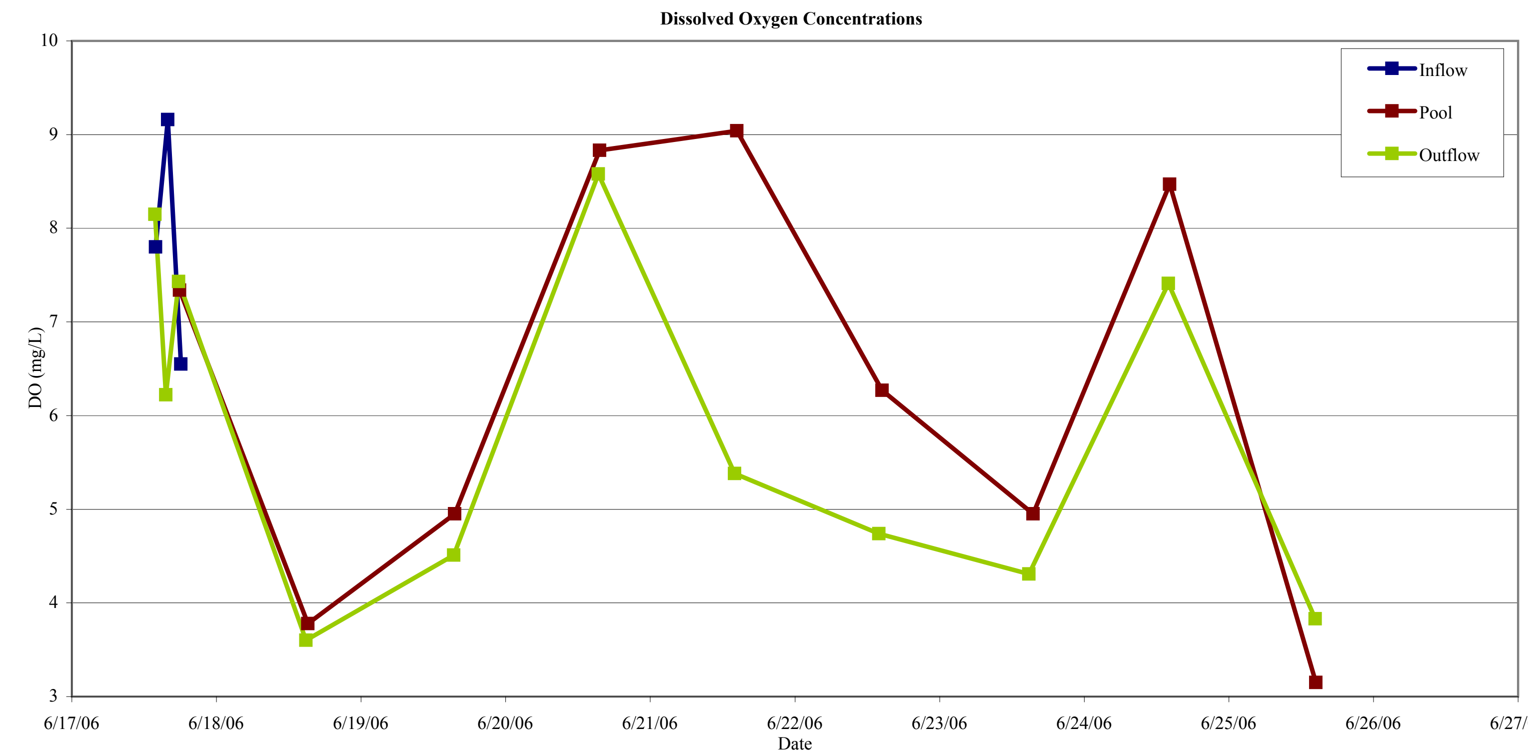
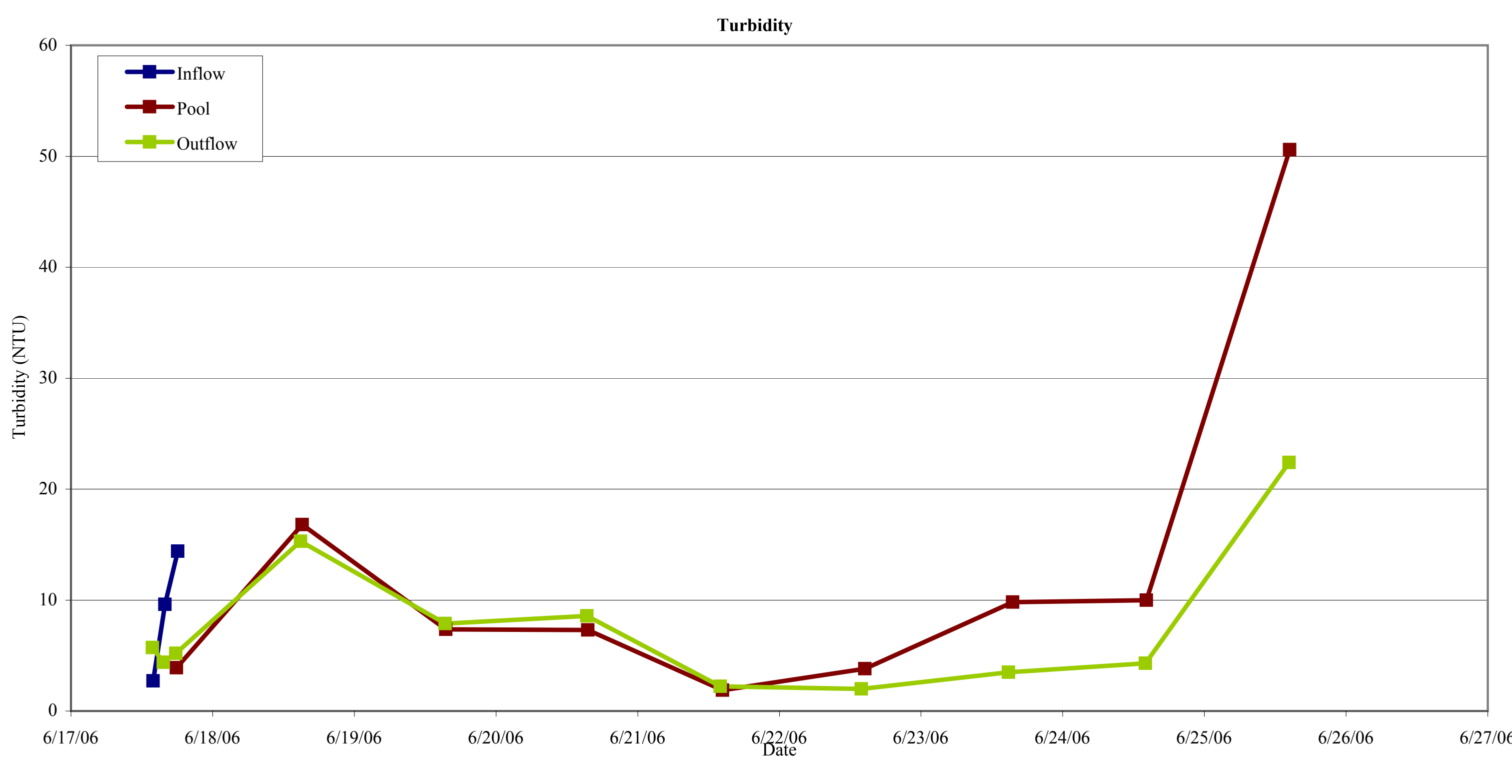
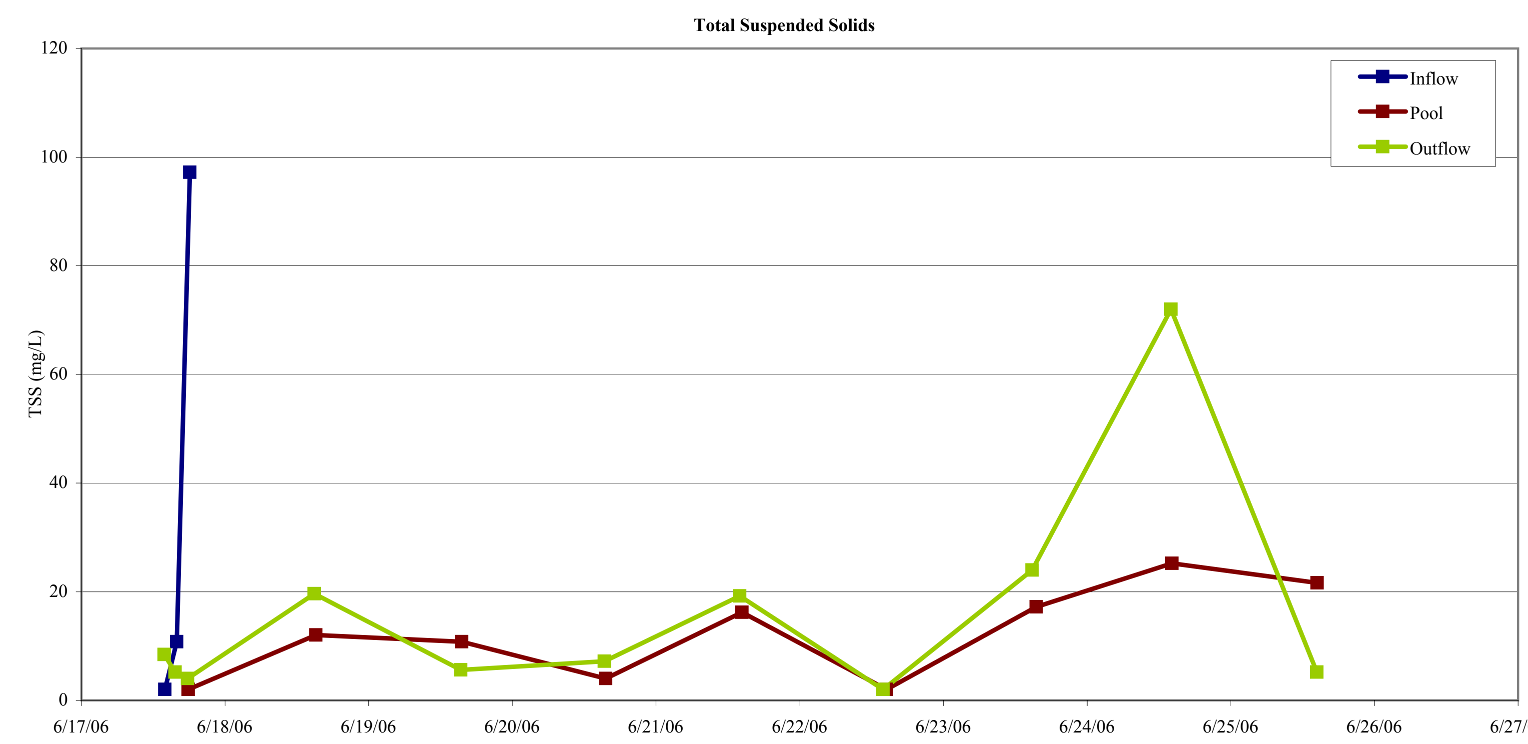


Figure 10: Additional Parameter Values Tested at Dry Basin 2 (Event 2)









On June 24, the concentration in the outflow was higher than that measured from the dense vegetation.

Table 14: *E. coli* Concentrations Tested at Various Locations near Dry Basins

Date	BMP	Pool Concentration (MPN/100ml)	Location
6/20/06	DB2	6677	Collected From Flood Overflow Berm
6/22/06	DB2	87	Collected From Heavily Vegetated Region of Pool
6/24/06	DB2	54	Collected From Heavily Vegetated Region of Pool

In summary, the differences between the basins were most likely the result of the detention of storm water and the stabilization/maintenance of the systems. DB1 did not have sufficient storage pool development during either of the two events. This basin was designed as a conventional basin. Under this design, the basin should hold water for an average of 24 hours; however, even immediately after the storm events, storage was not observed. Although a small pool did form after repeated storms passed through the region, the basin was no longer discharging and the bacteria concentrations did not decrease in the pool over the storage period. Alternatively, DB2 formed a substantial pool during both events and the processes associated with detention were observed during this period of time. In addition, DB1 exhibited a large amount of sediment that had accumulated along the concrete channel and did not stabilize very well. Gully formation was observed along the slopes of DB1. This is likely to have played a large role in the accumulation of the sediments. Although this study is focused on the effect that these systems have on fecal pathogens, it is important to note that sediment is considered a pollutant and can have harmful effects upon receiving waters and the organisms that inhabit them.

5.5 EFFICIENCIES OF WET BASINS

The variables that determine the reduction of bacteria concentrations from wet basin systems are much different from those for dry basins. Wet basins will hold permanent volumes of water and depend on rainfall event frequency and volumes to determine the retention period. It is very important for wet basin to accomplish two goals to achieve high efficiencies. First, the basin needs to discharge the highest percentage possible of water that has been held from previous storms and prevent any short circuiting. Second, the system needs to take advantage of the natural processes that reduce fecal pathogen concentrations.

Before the runoff events were monitored, water samples were collected from the permanent pools to evaluate baseline concentrations. One sample was collected at WB1 and three samples were collected at WB2 over two days. The results are shown in Table 15. All concentrations ranged between 4 and 11 MPN per 100mL of water. The most recent rainfall event occurred about four days before sample collection (from July 9 to July 10, 2006) and accumulated 0.28 inches of rainfall. This indicates a low survival rate for fecal pathogens in the permanent pool since very low residual concentrations of indicator bacteria were found four days after a runoff event.

Table 15: Baseline Fecal Pathogen Indicator Concentrations at Wet Basins

Date	BMP ID	Permit Number	Project Name	Location	Final Average	
					TC	EC
7/14/06	FC/WQ 1	8-0000055-7	Lakes of Pine Forest	Pool	148334	32
7/14/06	WB2	U033	Villages at Lakepointe	Pool	2684	11
7/14/06	WB1	8-0000134-0	Satsuma Lakes Villas	Pool	1425	4
7/14/06	WB2	U033	Villages at Lakepointe	Pool	2613	10
7/16/06	WB2	U033	Villages at Lakepointe	Pool	362	4

Notes:
EC – E. coli (MPN/100ml)
TC – Total Coliform (MPN/100ml)

The inflow pipes at both of the wet basins monitored are under the permanent surface level of the water. This was the most common design observed for wet basins in the region. To obtain a representative sample of inflow, all inflow samples collected during events four and five were collected from the underground storm sewers that collect the runoff at street level drainage inlets and discharge into the wet basin. The sewers were accessed through manholes. At WB2 the inflow rate was measured using the Marsh McBirney Flo-Mate to measure velocity and using the known pipe diameters and measured water elevation to calculate the flow area of the pipes. Unfortunately, this was not possible at WB1 which was designed much differently. This site had three inlet pipes, each of which has its own manhole. The pipes that discharge to and from the manholes became submerged during the runoff events and could not be accessed. Flow was assumed to be constant over the duration of the inflow. Because the inflow was only observed over periods of about two hours for events 4 and 5, this is likely to be an accurate assumption.

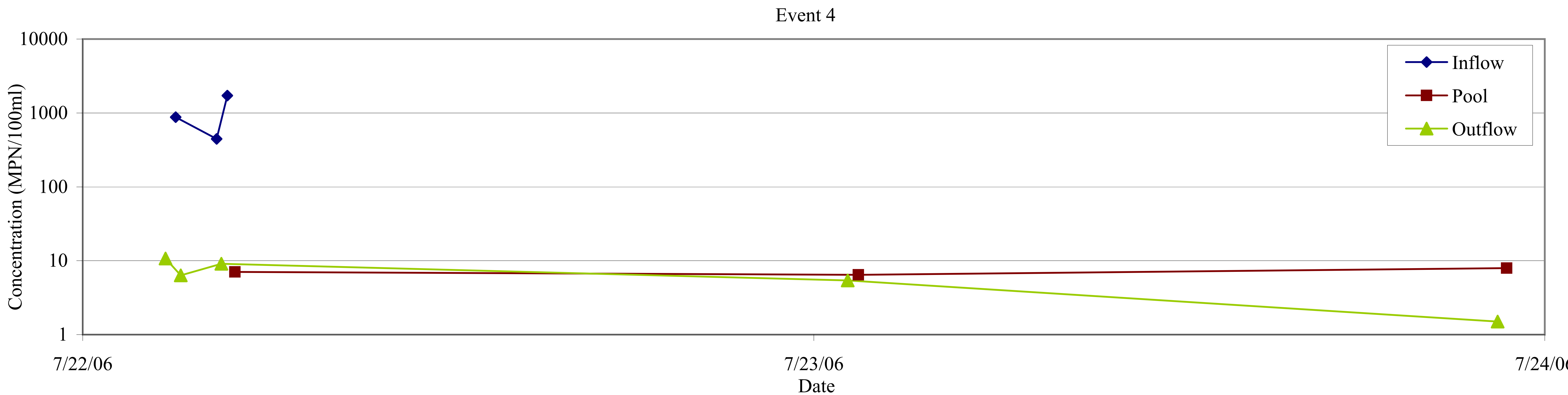
Wet Basin 1

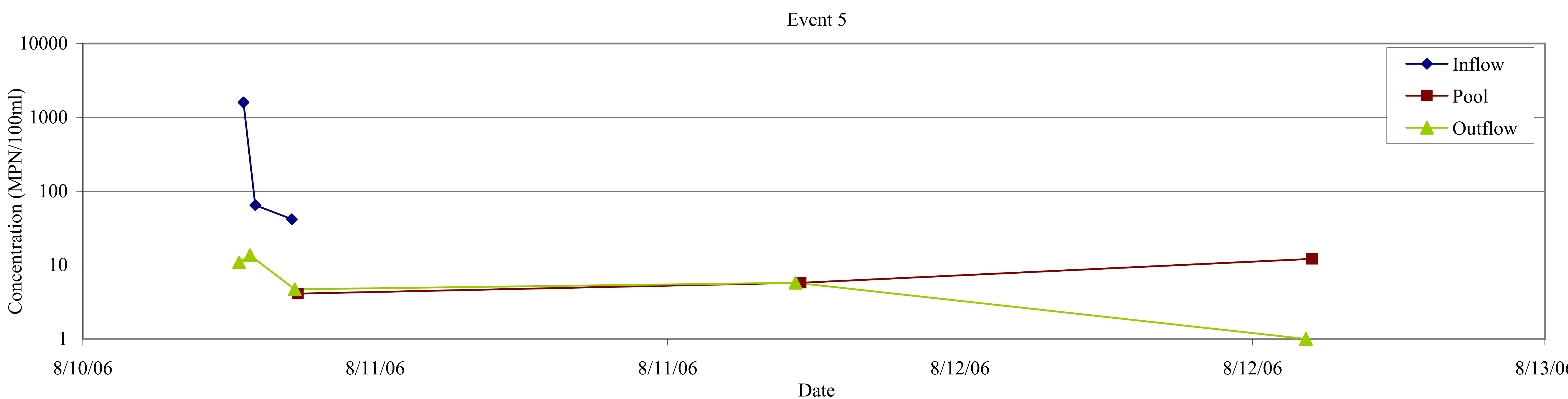
The wet basin located at Satsuma Lakes Villas (WB1) is a large retention pond with three inlets that discharge to a sediment forebay with a water fountain. The sediment forebay is connected to the permanent pool by a long channel that remains wet between and during runoff events. The permanent pool also has a running fountain and discharges to a ditch through a weir. The basin has an overflow bypass to prevent localized flooding in the case of large rainfall events. Ducks and other birds are often observed swimming and wading in the pond. In addition, fecal material has been observed during sample collection in the pool and near the outflow location. The pond has a natural bottom. Green algae are often observed around the edges of both the sediment forebay and permanent pool. Stormwater drains from the streets and lots into drainage inlets located along the streets. The inlets drain into an underground storm sewer system that drains into the wet basin through three inlet pipes that are located below the water surface.

The pool concentrations were collected from the channel that connects the two permanent pool volumes. The sample was collected near the outlet of the sediment forebay to the channel. Because the forebay is designed to encourage settling for the basin, this choice helps gather data to evaluate the effect that sedimentation may have upon the influent. Also, this helps to show whether bacteria from the influent will reach the channel and discharge into the permanent pool volume during a runoff event.

The first event monitored at WB1 (runoff event 4) took place over a three day period from July 22 to July 24, 2006. During the first day of the event, three rounds of samples were collected at the inlet and outlet and a sample was collected from the permanent pool. One round of samples was collected during each of the subsequent days. The concentrations at each of these locations and the flow weighted percent reduction for the event are shown in Table 16. The inlet concentrations ranged from 445 to 1718 MPN/100ml. These concentrations are low for stormwater runoff from residential areas. WB1 achieved greater than a 99% reduction for the event. Figure 11 shows a graph of the concentrations tested at WB1 during runoff event 4. The inflow concentrations were well above those measured at either the pool or the outflow. This shows that the wet basin was very effective at reducing the concentrations of *E. coli*. The outlet and pool concentrations remained fairly constant and low throughout the event and did not appear to be affected by the inflow concentrations. There are slight fluctuations initially but these are considered minor.

Figure 11: *E. coli* Concentrations at Wet Basin One





The second runoff event lasted from 8/10/2006 to 8/12/2006. The influent concentration as shown in Table 17 started off high and dropped significantly over the next two rounds. The outlet concentrations were very low throughout the event and decreased to 1 MPN/100ml by the third day of sample collection. The fecal pathogen reduction efficiency calculated for the second event is 95.5%, slightly lower than that for the first. This difference is probably the result of the lower inflow concentration geomean. The outflow concentration was close to that during the first event and the pool concentrations were the same as that during the first event. Non-point source concentrations often vary from runoff event to runoff event and the difference in inflow concentration is not considered to be of much consequence. Figure 11 shows a graph of the changes in E. coli concentration at the sample collection locations during the event.

Table 16: *E. coli* Concentrations and Removal Efficiency at WB1 (Runoff Event 4)

BMP	Date	Round	Inlet Concentration (MPN/100ml)	Pool Concentration (MPN/100ml)	Outlet Concentration (MPN/100ml)	Reductions Through Time*
WB1	7/22/06	1	876	-	11	99%
WB1	7/22/06	2	445	-	6	99%
WB1	7/22/06	3	1718	7	9	99%
WB1	7/23/06	1	-	6	5	99%
WB1	7/24/06	1	-	8	2	100%
WB1	Geomean		875	7	5	-
WB1	% Reduc		99.4%			

Notes: In the case of duplicates, values are calculated as the average of the two samples
* Reductions through time are calculated as: REC = (INFGM – OUT)/INFGM
where: RED is the percent reduction through time (%)
INFGM is the geometric mean of the inflow
OUT is the outlet concentration for each date and round

The outflow at WB1 was measured at the weir and calculated using the sharp-crested weir equation (Potter and Wiggert 2002). The flow ranged from 0.0092 cubic feet per second (cfs) to

0.019 cubic feet per second and discharge was observed over a period of about 44 hours. The outflow as shown in Table 18 and Figure 12 did not reach its peak rate of 0.19 cubic feet per second until July 23. By July 24th, the discharge rate had reduced to 0.012 cfs. The site received rain on that afternoon, so that the outflow for the first event could not be evaluated on July 25th. It was expected to have completely discharged the additional event one runoff volume before July 25th.

Table 17: *E. coli* Concentrations and Removal Efficiency at WB1 (Runoff Event 5)

BMP	Date	Round	Inlet Concentration (MPN/100ml)	Pool Concentration (MPN/100ml)	Outlet Concentration (MPN/100ml)	Reductions Through Time*
WB1	8/10/06	1	1600	-	11	93%
WB1	8/10/06	2	65	-	14	91%
WB1	8/10/06	3	42	4	5	97%
WB1	8/11/06	1	-	6	6	96%
WB1	8/12/06	1	-	12	1	99%
WB1	Geomean		163	7	7	95%
WB1	% Reduc		95.5%			

Notes: In the case of duplicates, values are calculated as the average of the two samples
* Reductions through time are calculated as: REC = (INFGM – OUT)/INFGM
where: RED is the percent reduction through time (%)
INFGM is the geometric mean of the inflow
OUT is the outlet concentration for each date and round

The outflow for the wet basin during the second storm event is shown in Table 19 and Figure 13. The outflow during this sample collection period was much higher than that measured during the first event. The outflow ranged from 0.030 cfs at the first sample collection time to a peak outflow of 0.32 cfs on August 10, 2006. The discharge was measured over a period of about 44 hours. By the last sample collection round on August 12th, the discharge had decreased to 0.0078 cfs.

Table 18: Discharge from WB1 During Event 4 (7/22/2006 to 7/24/2006)

Location	Date + Time	Water Depth (Above Weir Base) (ft)	Weir Base Height (ft)	Weir Width	C_d	Flow (cfs)
SAT-O-1	7/22/2006 17:43	0.05	0.92	0.25	0.614348	0.009187
SAT-O-2	7/22/2006 18:13	0.06	0.92	0.25	0.615217	0.012093
SAT-O-3	7/22/2006 19:33	0.06	0.92	0.25	0.615217	0.012093
SAT-O-1	7/23/2006 16:07	0.08	0.92	0.25	0.616957	0.018672
SAT-O-1	7/24/2006 13:27	0.06	0.92	0.25	0.615217	0.012093

Sharp-Crested Weir: (Potter, Merle C. and David C. Wiggert, **Mechanics of Fluids**, 2001)

$$Q = C_d \frac{2}{3} (2g)^{1/2} b Y^{3/2}$$

Notes:

C_d - Discharge Coefficient (0.61)

Q - Flow Rate (cfs)

g - acceleration due to gravity (ft^2/s)

b - weir width (feet)

Y - vertical distance from top of weir to free surface (feet)

Figure 12: Discharge from WB1 During Event 4 (7/22/2006 to 7/24/2006)

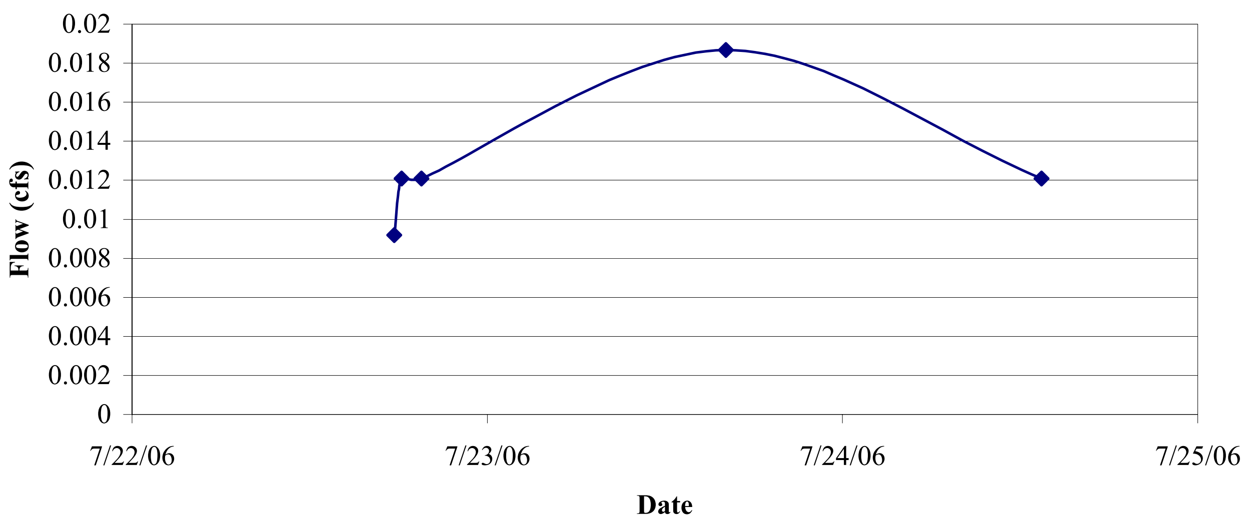


Table 19: Discharge from WB1 During Event 5

Location	Date + Time	Water Depth (ft)	Water Depth (Above Weir Base) (ft)	Weir Width	C_d	Flow (cfs)
SAT-O-1	8/10/2006 18:25	1.03	0.11	0.25	0.619565	0.030232
SAT-O-2	8/10/2006 18:52	1.03	0.11	0.25	0.619565	0.030232
SAT-O-3	8/10/2006 20:42	1.04	0.12	0.25	0.62	0.032339
SAT-O-1	8/11/2006 17:15	0.98	0.06	0.25	0.615217	0.012093
SAT-O-1	8/12/2006 14:12	0.97	0.04	0.25	0.613913	0.007838

Sharp-Crested Weir: (Potter, Merle C. and David C. Wiggert, **Mechanics of Fluids**, 2001)

$$Q = C_d \frac{2}{3} (2g)^{1/2} \, b \, Y^{3/2}$$

Notes:

C_d - Discharge Coefficient (0.61)

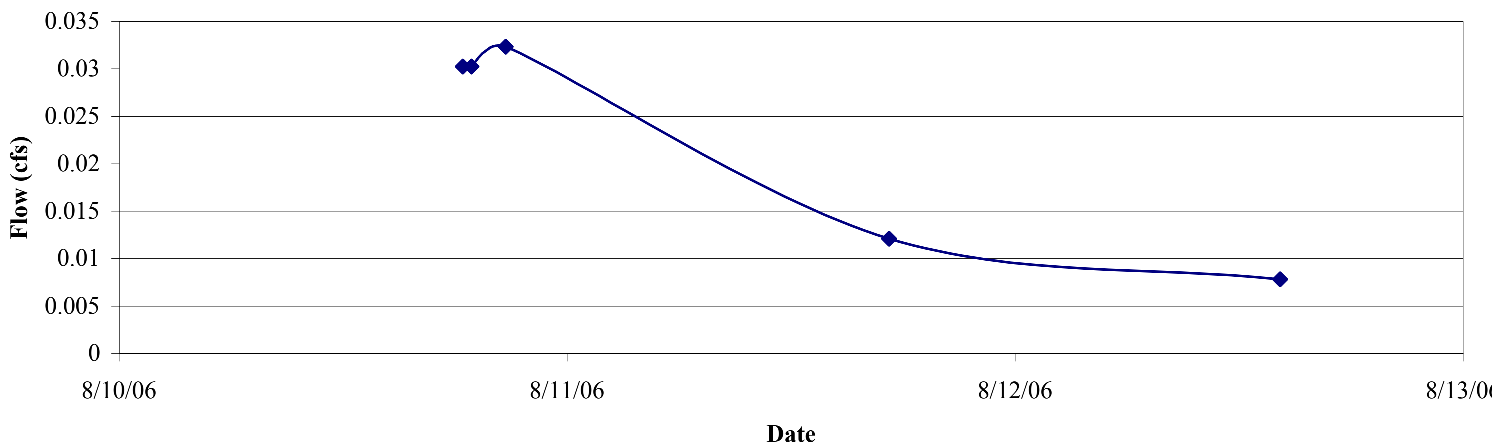
Q - Flow Rate (cfs)

g - acceleration due to gravity (ft^2/s)

b - weir width (feet)

Y - vertical distance from top of weir to free surface (feet)

Figure 13: Discharge from WB1 During Event 5



Wet Basin 2

Wet Basin 2 (WB2) was not designed specifically for water quality treatment. The wet basin was constructed before the adoption of the water quality requirements for new development as part of the phase 2 requirements of the NPDES program. The basin was chosen because it met the design requirements designated by JTF; however, it offers several significant differences from WB1. As in the sampling conducted at dry basins, the evaluation of differences between the systems will help in the understanding of the different design strategies for the systems. First, WB2 did not have a functioning water fountain during reconnaissance of sample collection sites while WB1 did. The effect of fountains on water quality in wet basins is a topic of interest. In addition, the basin did not have a distinct sediment forebay as was observed in many of the other wet basin designs in the Houston Metropolitan Area. In addition, the wet basin was older than most of the wet basins permitted yet it is maintained very well.

The first sample collection event at WB2 (runoff event 3) occurred on July 18, 2006. While on site collecting data for the die-off study, an isolated low intensity storm passed over the site. Since sample collection was ongoing, samples of the inflow, pool, and outflow were collected to help develop an initial idea of the concentrations that would be obtained during the other full events. For this one event only, the inflow was obtained from a culvert located along the sides of the streets. The culvert from which samples were obtained drained directly to the manhole from which samples were later collected for events four and five. The pool sample was collected as during each of the subsequent events from the northeast side of the permanent pool. The basin discharges through one grate inlet that is located on the south side of the pond and outflow was collected here.

The results of the sample collection during this event are shown in Table 20. The *E. coli* concentration is very high compared to that collected during any of the other events at any of the other basins (including both wet and dry basins). The pool concentration was slightly higher than what had been seen during the baseline sample collection; however, the concentration was still well under the single sample standard regulated for *E. coli* concentrations at contact recreation surface waters. The outflow was very low, even slightly lower than that observed during the baseline sample collection. According to these results, the wet basin had a removal efficiency of 99.99% for this event. The event had an accumulation of 0.04 inches from which an estimated volume of 0.07 acre-feet was produced. This is a relatively small event and shows that high reductions can be achieved at wet basins for smaller events.

Table 20: *E. coli* Concentrations at WB2 during Runoff Event 3

Date	BMP ID	Permit Number	Project Name	Location	Final Average	
					TC	EC
7/18/06	WB2	U033	Villages at Lakepointe	Inflow	241900	13450
7/18/06	WB2	U033	Villages at Lakepointe	Pool	1201	16
7/18/06	WB2	U033	Villages at Lakepointe	Outflow	1601	2
% Reduction	WB2	U033	Villages at Lakepointe	-	>99.34%	99.99%

Notes:
EC – E. coli (MPN/100ml)
TC – Total Coliform (MPN/100ml)

The second sample collection event at WB2 (Event 4) occurred from July 22 to July 24, 2006. The fecal pathogen removal efficiencies are shown in Table 21. The inflow concentrations discharged from the residential pond were, as in event three, relatively high. These ranged from 1.6×10^4 to 2.4×10^5 MPN/100ml. Unlike the pool and discharge concentrations during the storm at WB1, the pool and the outlet concentrations were affected by the high concentrations of inflow to the system. As noted previously, the dry weather baseline for this location ranged from 11 to 4 MPN/100ml measured over three samples. The concentrations discharged from WB2 during Event 4 ranged from 68 to 7100 MPN/100mL. The pool also showed high concentrations ranging from 99 to 245 MPN/100mL. The pool and outlet concentrations both appeared to peak during the first round of sample collection and decreased slightly over the next two days. The efficiency of the system was calculated to be 98.8%. A graph of the changes in E. coli concentration at each of the sample locations is shown in Figure 14. The high discharge and subsequent drop off is very evident.

Table 21: *E. coli* Concentrations at WB2 during Runoff Event 4

BMP	Date	Round	Inlet Concentration (MPN/100ml)	Pool Concentration (MPN/100ml)	Outlet Concentration (MPN/100ml)	Reductions Through Time*
WB2	7/22/06	1	7.93E+04	-	198	100%
WB2	7/22/06	2	2.42E+05	-	879	99%
WB2	7/22/06	3	1.64E+04	245	7105	91%
WB2	7/23/06	1	-	230	68	100%
WB2	7/24/06	1	-	99	231	100%
WB2	Geomean		8.07E+04	1.77E+02	9.52E+02	-
WB2	% Reduc		98.8%			

Notes: In the case of duplicates, values are calculated as the average of the two samples
* Reductions through time are calculated as: REC = (INFGM – OUT)/INFGM
where: RED is the percent reduction through time (%)
INFGM is the geometric mean of the inflow
OUT is the outlet concentration for each date and round

Runoff event five occurred from August 10 to August 12, 2006. Rain gage accumulations are not yet available for this storm from the HCOEM but accumulations in the region of about 0.2 inches were observed. Rainfall lasted several hours and at the time that field personnel arrived at the site, steady light drizzle was observed.

Table 22 shows the concentrations measured at each of the sample collection locations at WB2 during the event. The inlet concentrations were much lower than those observed during events three and four at the site. These ranged from 79 to 1600 MPN/100ml. Along with the low influent concentrations, a much smaller increase in pool and outflow concentrations was observed for this event than for event four. Even though the discharge concentrations were also much lower than those of event four, because of the low influent, the efficiency of the system was slightly less at 97.5 %. In Figure 14, the lack of a strong initial effluent concentration peak can be observed especially in contrast to the peak that occurred during event four.

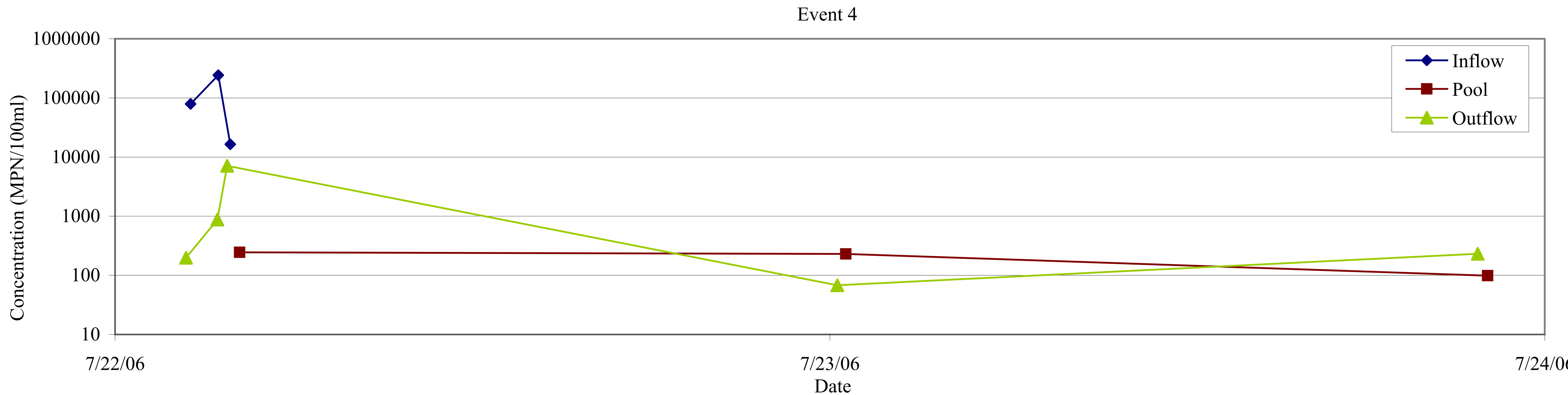
Table 22: *E. coli* Concentrations during Runoff Event 5

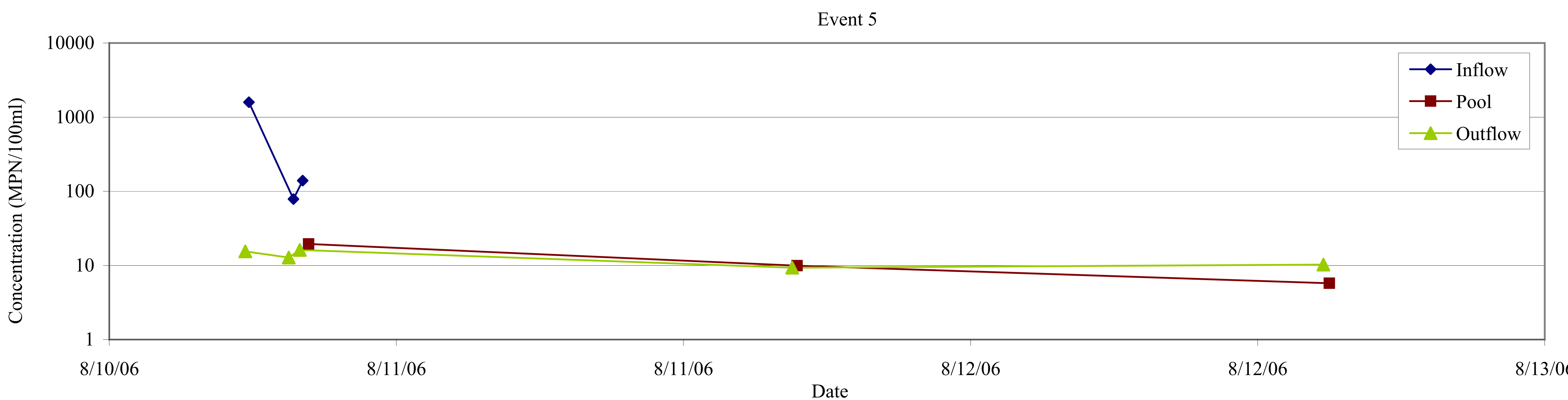
BMP	Date	Round	Inlet Concentration (MPN/100ml)	Pool Concentration (MPN/100ml)	Outlet Concentration (MPN/100ml)	Reductions Through Time*
WB2	8/10/06	1	1589	19	15	91%
WB2	8/10/06	2	79	10	13	92%
WB2	8/10/06	3	139	6	16	90%
WB2	8/11/06	1	-	-	9	94%
WB2	8/12/06	1	-	-	10	94%
WB2	Geomean		5.32E+02	6.00E+00	1.31E+01	-
WB2	% Reduc		97.5%			

Notes: In the case of duplicates, values are calculated as the average of the two samples
* Reductions through time are calculated as: REC = (INFGM – OUT)/INFGM
where: RED is the percent reduction through time (%)
INFGM is the geometric mean of the inflow
OUT is the outlet concentration for each date and round

Throughout sample collection at WB2, ducks and many other birds were observed in and around the permanent pool. No effect upon the pool and upon the effluent concentrations could be directly attributed to these birds. These should have increased concentration during dry if direct deposition had been occurring and this was not the case. Bird fecal material was noticed

Figure: *E. coli* Concentrations at Wet Basin Two





near the outfall. They may have increased effluent concentrations but fluctuations in the effluent are consistent with the inflow concentrations measured.

CHAPTER 6

SUMMARY AND FUTURE WORK

A database of the permitted BMPs in the Houston metropolitan area was created from data obtained through Harris County and the University of Houston. The data show that dry basins are the most common BMP implemented in the region. Wet basins are the second most common type believed to have a significant impact on pathogen concentrations. Although grassy swales, vegetative filter strips, and wetlands are present, these are much less commonly implemented.

A total of two dry and two wet basins were selected from the database based on design considerations and accessibility. Samples were collected at two dry basins and two wet basins during five runoff events. The flows and bacteria concentrations were calculated to determine the efficiencies of the systems. Mixed results were observed for the detention basins that can be explained by the different designs tested. The wet basins showed high and consistent bacteria removal efficiencies during the three runoff events that were tested.

Detention basin 1 had net fecal bacteria indicator increases in the outflow as compared to the inflow of the system. This is likely the result of two important factors. First, sediments that had accumulated in the basin from previous events had high fecal pathogen indicator concentrations. Resuspension of the sediments was observed during sample collection activities. Second, limited pool development was observed at the site during the runoff events. Bacteria die-off and sedimentation are believed to be the predominant pathways by which concentrations are reduced and these occur during the storage of storm water. Detention basin 2 showed fecal pathogen indicator reductions of 67 and 70 percent for two runoff events that were tested.

The wet basins showed higher fecal pathogen indicator removal efficiencies than those of the detention basins. Wet basin 1 had efficiencies of 99% and 96% during the runoff events tested and wet basin 2 had efficiencies of 99% and 98%. Birds were observed using the systems, however, the efficiencies of the basins indicate that these are not a significant source of fecal pathogens.

Activities for the next quarter will focus on additional data analysis and sample gathering.

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APPENDIX A

QUALITY ASSURANCE PROJECT PLAN

(Electronic Version)

APPENDIX B

PERMITTED BMP DATABASE

(Electronic Version)

APPENDIX C

STANDARD OPERATING PROCEDURES

FIELD STANDARD OPERATING PROCEDURES
(FOR BMP PROJECT)
SOP B-15

AT EACH STATION:

A. Record (in the field book):

1. The station location and Station ID
2. The place where sample is collected (i.e. Outlet, Storage Pool, or Inlet).
3. The sample collection round number
4. The date
5. The time the measurements are initiated and ended
6. Depth at which samples are obtained
7. The name(s) of the person(s) measuring the flow
8. The name(s) of the person(s) collecting samples
9. Water appearance (For example: clear, turbid, etc.)
10. Weather (Including the number of days since rain event)
11. Biological activity (For example: algal growth, birds, fish, etc)
12. Unusual odors
13. Watershed or nearby activity (For example: nearby construction, cattle, etc)

B. Collect water sample for bacteria analysis (following the procedure shown below) while causing as little disturbance as possible to the sample collection water and/or storage pool.

Notes: Collect water samples first at the Outlet, second at the Storage Pool (if one exists), and last at the Inlet.
Water samples should be collected before any other work is done at a site unless holding time limits would be compromised.

C. Collect water samples for TSS.

D. Record Conductivity, Dissolved Oxygen, pH, Salinity, Temperature, and Turbidity using the YSI probe.

E. If there is discharge into or out of the BMP, take flow measurements (following one of the procedures included below).

F. When collecting a storage pool sample, measure the pool depth.

PROCEDURES:

B. COLLECTION OF WATER SAMPLE (AMBIENT) FOR BACTERIA ANALYSIS:

1. Label whirl-pak bags with the site/station number, the sample location, the sample collection round, and the date of collection.
2. Collect the sample of water with a sterile container at the centroid of flow. When collecting the storage pool sample, collect the sample at a depth of 0.3 m (1ft), or, for shallow pools, at roughly half the depth. Record the depth at which the sample was collected.
3. Pour the water from the sterile container into each of three whirl-pak bags. Avoid splashing. Leave an air bubble in the sealed whirl-pak bag to help for mixing of the sample well in the lab.
4. Place the whirl-pak bags into an ice chest with plenty of ice to keep the samples cool.
5. Analyze the samples following the **IDEXX *E. Coli*/Enterococci Analysis SOP**.
   Note - analysis must begin within 6 and must be completed within 8 hours of sample collection (TCEQ Surface Water Quality Manual). If for any reason the samples are not transported to the lab within 6 hours, this must be noted and the samples must still be analyzed within the 8 hour time limit.

C. COLLECTION OF SAMPLES FOR TSS ANALYSES:

1. Label TSS bottle with the site/station number, the sample location, the sample collection round, and the date of collection.
2. Collect the sample of water with the container at the centroid of flow. When collecting the storage pool sample, collect the sample at a depth of 0.3 m (1ft), or, for shallow pools, at roughly half the depth. Record the depth at which the sample was collected.
3. Place the bottle into an ice chest with plenty of ice to keep the samples cool. Samples must be shipped to North Water District Lab for TSS analysis following the sample shipping SOP.

D. RECORD CONDUCTIVITY, DISSOLVED OXYGEN, pH, SALINITY, TEMPERATURE, AND TURBIDITY:

1. Place the calibrated YSI into the stream ensuring that each of the probes is submerged (Note – YSI must be calibrated in the lab previous to measurement; the calibration process is detailed in a separate SOP calibration guide).
2. Record each of the parameters in the field log book.

E. FLOW MEASUREMENT:

Several different methods may have to be employed when measuring flow at a BMP. The field personnel will have to chose the appropriate method to use. The methods should be chosen with consideration of the requirements of the site and access, safety concerns, and to try and ensure the most accuracy.

When collecting flow measurements from an inlet/outlet pipe above the water surface (common at a dry basin), one or a combination of several methods can be used according to the site specifics:

Using the Manning's Equation Method:
1. Choose a location where channel characteristics such as the slope parallel and perpendicular to flow are known or can be easily measured.
2. Measure the water surface elevation at the location where the flow will be calculated.
3. Measure the width of the water surface.

Using the Marsh McBirney Flo-Mate 2000:
1. Measure the pipe diameter or channel geometry.
2. Measure the depth of flow.
3. Attach the Marsh McBirney sensor to the metal rod or a modified survey rod.
4. Lower the sensor to 60% of the flow elevation.
5. Record the velocity value after the gauge stabilizes (allow a minimum period of 20 seconds before taking the measurement). Record the locations (depth and horizontal distance from bank) of each of the measurements.

Using Volume-Based Method:
1. This method can be most accurately and easily used with an inflow or outflow pipe that is not discharging at an extremely high flow rate.
2. Collect the flow from the inflow or outflow pipe over a short period of time using a container that is either graduated or has a known volume.
3. Use a stopwatch to measure the time over which flow is collected.
4. Record the time of flow collection and the volume of water that was collected.

Using the Float-and-Stopwatch Method:
1. Place the survey rod or other distance measuring device parallel to the flow at the pipe or channel.
2. Place an object in the water that can be easily and accurately monitored. The object should float so that it is partially submerged in the water to ensure that it is not easily affected by wind and that it is affected by the variation of velocities at different depths.
3. Use a stopwatch to measure the time that it takes for the object to travel a known distance along the survey rod.

4. Measure the pipe diameter or channel geometry.
5. Measure the water surface elevation.

When collecting from a submerged inlet/outlet (such as may be found at a wet basin or flood control/water quality basin), one or a combination of several methods can be used according to the site specifics:

Measuring flow from the storm sewer system:

1. Use the manhole cover lifter tool to remove the manhole cover from the manhole(s) closest to the inflow pipe.
2. For each pipe that discharges to the manhole repeat these steps:
3. Measure the diameter of the pipe.
4. Measure the depth of flow.
5. Attach the Marsh McBirney sensor to the metal rod or a modified survey rod.
6. Lower the sensor to 60% of the flow elevation.
7. Record the velocity value after the gauge stabilizes (allow a minimum period of 20 seconds before taking the measurement). Record the locations (depth and horizontal distance from bank) of each of the measurements.

When collecting from a weir or grate inlet (such as may be found at the outlet of a wet basin, flood control/water quality basin, or other BMP with a permanent pool of water):

Measuring flow using a weir:

1. Measure the elevation of the discharge above the weir notch.
2. Measure the dimentions of the weir: elevation of the base of the weir notch and the width of the weir notch.

Measuring flow at a grate inlet:

1. Measure the surface elevation of the water and the elevation of the grate or the depth of the water flowing above the grate.
2. Measure the dimensions of the grate: width and length of the grate.

IDEXX E. Coli*/Enterococci *Analysis

Prior to receiving Samples in the Lab:

1. LABEL: Each vessel should be labeled with the wastewater plant/station, the sample dilution and the time of sample collection (either early or late) with a permanent Sharpie marker or address label stickers. Address label stickers should also be prepared for the IDEXX Trays and placed on trays prior to receive the samples.

Labeling Protocol:
Location – Dilution – Replicate
Location:
BMP Type & Site ID
Local site (influent, effluent, storage volume)
Sequence number (first, second sample, etc.)
Dilution:
1, 10, 100, or 1,000
Sample ID:
A, B, or C for the set of replicates

Example: WET POND – 2002458895
Influent - Third

2. PREPARE DILUTIONS: The IDEXX Analysis will be performed in triplicate for all sampling (unless otherwise specified). A total of nine vessels should be prepared for each sample as follows:
   - 1:100 dilution: Place 99 mL of sterile water into vessels. If using the re-pipettor, check the accuracy of the pipet every time a new media bottle of sterilized, DI water is used.
   - 1:10 dilution: Place 90 mL of sterile water into vessels. If using the re-pipettor, check the accuracy of the pipet every time a new media bottle of sterilized, DI water is used.
   - 1:1: No sterile water will be placed in these vessels.

   When dispensing the DI water, check the light on the cylinders. The green lights indicate that conductivity of the water is within an appropriate range for DI water. If either of the lights are red, note this in the IDEXX log book and do not use the DI water. Notify Louis (UH Lab Manager) and discontinue DI water use until light returns to green.

3. SET OUT REAGENT: Colilert reagent will be used for all samples. One reagent package should be set out with the bottles and trays for each sample. This is to ensure that all samples receive the proper amount of reagent.

Receive Samples:

4. SIGN CHAIN-OF-CUSTODY: Sign and date the chain of custody (COC), acknowledging that you have received the samples.

5. RECORD IN LOG BOOK: In the Receiving log, note the date, time, initials of the person receiving the samples, temperature of the samples from the temperature tester, and number and type of samples received. Confirm that all samples in the cooler are found on the COC. Include any samples that need to be analyzed for TSS.

6. TURN ON SEALER. Turn on the sealer so that it will be warmed up by the time the samples are ready to seal. The sealer should be turned on at least 10 minutes prior to running the samples through the machine. The sealer is ready to use when the green light comes on.

After Samples have been received:

7. PREPARE SAMPLE: Shake Whirl-pak bags well to fully mix the water samples. Prepare each sample as follows:
    - 1:1,000 dilution, ONE OF TWO WAYS:
        a. Place 0.1 mL of sample into vessels with 99.9 mL sterile water (use 1:100 dilution bottle and complete using 0.1 – 1 mL pipette).
        b. Place 10 mL of sample into 1:10 dilution bottle (i.e., 90 mL of sterile water). Shake that sample very well and draw 1 mL of sample/water mixture and place into 1 new 1:100 mL (i.e., 99 mL sterile water) bottle. Do this if 0.1 to 1 mL pipette is not available.
    - 1:100 dilution: Place 1mL of sample into vessels with sterile water using pipette with sterile pipette tip. A new tip should be used for each sample.
    - 1:10 dilution: Place 10 mL of sample into vessels with sterile water using pipette with sterile pipette tip. A new tip should be used for each sample.
    - 1:1: 100 mL of sample will be poured into the vessels with sterile water directly from the Whirl-pak bags.

    Note the date, time of dilution commencement, time of reagent addition, reagent lot #, the sample IDs, time of sample incubation, incubation temperature and your initials in the IDEXX Log.

8. PREPARE QUANTI-TRAY: Snap open the reagent by folding back the top at the line and pour into the sample vessels. Be careful not to touch the vessel to the opening of the packet. Cap the vessel and shake until dissolved completely. No more than 30 minutes should pass between the time the reagent is added and the trays are incubated.

    Squeeze the Quanti-Tray into a "U" shape with the well side facing your palm and pull back the foil tab to open the tray. Pour the sample into the tray, avoiding contact with the foil tab. Tap the small wells 2-3 times to release any air bubbles. Allow foam to settle. Ensure that the labeled dilution bottle matches up with the labeled Quanti-Tray.

9. SEAL THE TRAYS: Prepare all sample Quanti-Trays before running through the sealer, or if a large amount of samples have been prepared, then the samples can be prepared in sets to minimize time between reagent addition and incubation. Place the Quanti-Tray in the rubber insert. Place the rubber insert in the input tray of the sealer with the large cutout facing away from the sealer and the overflow basin facing upwards. Place the tray in the sealer and with moderate pressure, push it through until the machine catches the insert.

10. INCUBATE: Once all trays in the set have been sealed, place them into the incubator. Incubate trays for 24 hours. Note the temperature of the incubators and incubator ID in the IDEXX Log ***prior*** to opening the door.

    Note - For all *E. coli* samples, the incubator temperature must be maintained at 35 +/- 0.5°C. (Specific incubator(s) will be designated for incubation of *E. coli* samples when more than one method is required. These incubators will be maintained at the proper temperature).

11. CLEAN UP: Pour any remaining samples down the laboratory sink and rinse down the sink with clean water from the tap. Throw the Whirl-pak bags in the trash. Spray down the lab bench with disinfectant spray or wipe down with alcohol.

Reading the Samples:

12. REMOVE SAMPLES: The samples can be read at 24 hours and up to 28 hours after the sample incubation period begins.

13. READ SAMPLES: Note the total number of yellow wells in the IDEXX Log. If unsure about whether the sample is positive, then reincubate as shown below.
    - If there is no yellow color, the test is negative.
    - If the well has a yellow color, then the presence of total coliforms is confirmed. If the color is not uniform, mix the sample by turning it upside down and recheck the color.
    - If the well has a slight yellow color, the Quanti-Tray may be incubated for an additional 4 hours (but no more than 28 hours total incubation). If the sample is positive for total coliforms, then the color will intensify. If the color does not intensify after additional incubation, then the sample is negative.

14. ULTRA-VIOLET: If some of the sample wells are yellow, check the Quanti-Tray for fluorescence by placing it in the UV Cabinet. Look inside the cabinet and identify any fluorescence. If there is questionable fluorescence, then you can reincubate the tray for up to 28 hours total incubation. This fluorescence indicates the presence of *E. coli*. Record total number of fluorescent wells in the IDEXX Log.

15. CLEAN UP: Place trays in a regular black plastic bag to be thrown away in the garbage dumpster at the end of each day.

Quality Control in lab:

- Blanks: The sterile water must be analyzed ONCE PER DAY just like another sample to ensure that there is no contamination. If using pre-prepared dilution bottles, a 1:100 bottle can be used for the blank check. If large amounts of samples are being analyzed, then there may be a need to analyze more than one blank. This will be determined based upon the lab analysts' professional judgment.

- Replicates: Samples will be run in duplicate or triplicate for each sample. This will be specified before sample analysis begins

- Concurrent reading of IDEXX trays: Each month, all analysts must read the same IDEXX tray to confirm that everyone is reading the samples correctly.

- IDEXX Standards: Must be run on each new lot of IDEXX reagent (see note, below).

QC in the field and to be analyzed in the lab:

  - Equipment Blanks: Sterile water that has been used to rinse the sampling equipment and analyzed to detect equipment contamination. This is analyzed at least once every 20 samples.

  - Field Duplicates: Samples that have been collected by the field personnel to document the reproducibility the laboratory analysis. This is analyzed at least once every 20 samples.

APPENDIX D

SITE PICTURES

(Electronic Version)